NA-66-57

PHASE I SUPPLEMENT REPORT

TITANIUM S-IC SKIN SECTION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

NORTH AMERICAN AVIATION, INC. / LOS ANGELES DIVISION

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NA-66-57

SERIAL NO. 33

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

PREPARED BY

A. G. Jones

A. G. JONES
PROJECT MANAGER

APPROVED BY

G. B. Lewis

G. B. LEWIS
PROGRAM MANAGER

DATE 24 March 1966
NO. OF PAGES

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FOREWORD

The activities, accomplishments, and tests described in this report were made during the time period from 8 November 1965 to 11 March 1966 and constitute a supplement to the Phase I effort as originally scheduled for the development program. This report, together with NA-65-1043 and NA-65-1004, completes the Phase I requirements of NASA/MSFC Contract No. NAS8-20530, "Titanium S-IC Skin Section."

ABSTRACT 35230

This report describes the design and fabrication of two roll diffusion bonding test packs and the laboratory evaluation of the titanium panels produced from those packs.

The report also describes the rolling of a steel plate, representing a full-scale pack, to establish feasibility guide lines for production in Phase III of the NASA development program.

Pertinent design drawings, charts, photographs, and other illustrative material are included.

SUMMARY

After the evaluation and analysis of the first four titanium test panels, a plan was formulated for the design and fabrication of Packs E and F to incorporate acquired learning and to simulate, as as nearly as possible, the proposed full-scale Phase III packs.

In design, Packs E and F were identical with one exception. A separator sheet of commercially pure titanium foil was placed under each cover plate of Pack E, but in Pack F, a foil sheet was placed only under the lower cover plate. The principal reason for omitting the upper foil was to provide uninterrupted exposure of steel for the leaching process in one pack for comparison purposes.

In the rolling process, both packs were programmed for the same sequence of operations, with the exception that Pack E was water spray quenched, while Pack F was air-cooled. The intent was to determine the relative effects of quenching and air-cooling on flatness, surface condition, and duplex annealed properties of the 8Al-1Mo-1V titanium alloy panels.

To prepare for the roll diffusion bonding of the full-scale panels in Phase III of the program, a steel plate 7 x 108 x 165 inches was heated to 1825°F, rolled in a programmed sequence to a 60 percent reduction, and air cooled. Finished thickness was within 0.005 inch of target dimension, and cooling occurred within the requirements for duplex annealing.

Dimensional inspection and analysis of the panels from Packs E and F, plus laboratory testing and evaluation, have revealed or emphasized certain procedures and techniques which help to improve the quality of the diffusion bonded panel, as well as certain other methods which should be abandoned or modified.

Principal conclusions resulting from the Phase I supplementary effort are as follows:

1. Water quenching is not necessary to obtain the duplex annealed condition; it creates stresses within the titanium panel which cause warpage, and contributes to surface cracking in the titanium material.

2. Air-cooling can result in flat panels and in the duplex annealed condition.

3. A radius on steel filler bar edges is recommended to ensure a satisfactory fillet in the titanium panel.

4. To improve the flow of material during rolling, a pack should be brought to temperature and then soaked one hour for each inch of thickness.

5. It would be desirable in the design of a pack to avoid a straight line of spearation parallel to the axis of the rolls.

6. A titanium foil sheet under each cover plate is recommended for easy removal of the cover plates after rolling.

7. Fluorescent penetrant inspection is recommended for revealing bond area cracks.

8. Repair welds are readily made if necessary in bond joints.

9. During the hot rolling operations, there is a lateral expansion of the pack which amounts to as much as 4 percent of the initial width. Furthermore, this expansion is not uniform along the full length of the pack, being more pronounced in the center than at the ends.

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Section I

FABRICATION OF TEST PACKS E AND F

The design of Test Packs E and F, shown in figure 1, incorporated features which resulted from previous pack experience. For example, laboratory analysis of the titanium panels produced from the first four packs indicated the presence of contamination attributable to the unmachined steel filler bars. To minimize, if not eliminate, this condition all of the steel filler bars in Packs E and F were machined on all surfaces.

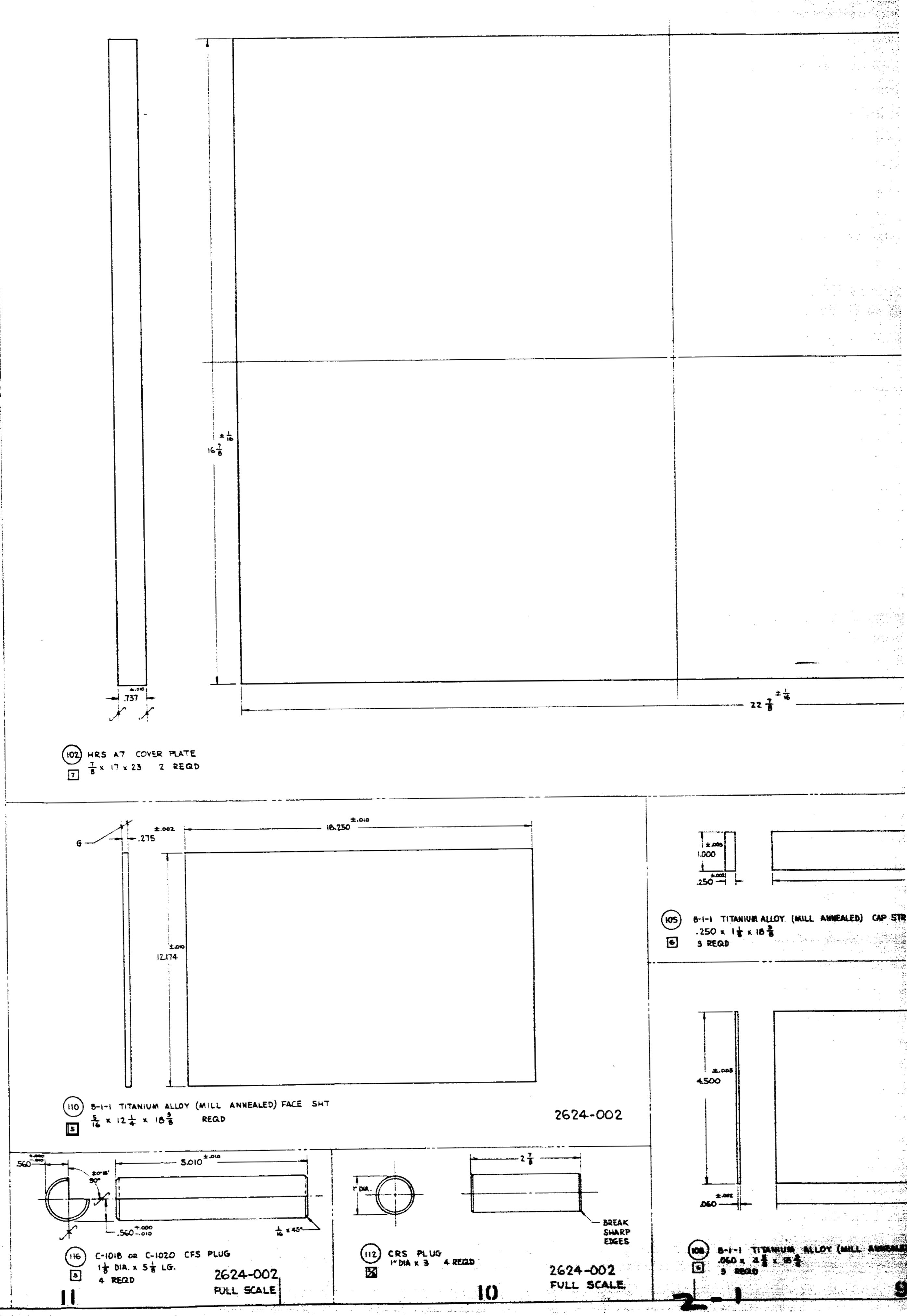
Microexamination of the bond joints in the first four titanium test panels showed sharp notches and incipient cracks which, it was determined, resulted from chamfering of the filler bars. To produce rounded fillets in Panels E and F, the filler bars were carefully radiused to a full 1/32 inch on edges which contacted titanium joints.

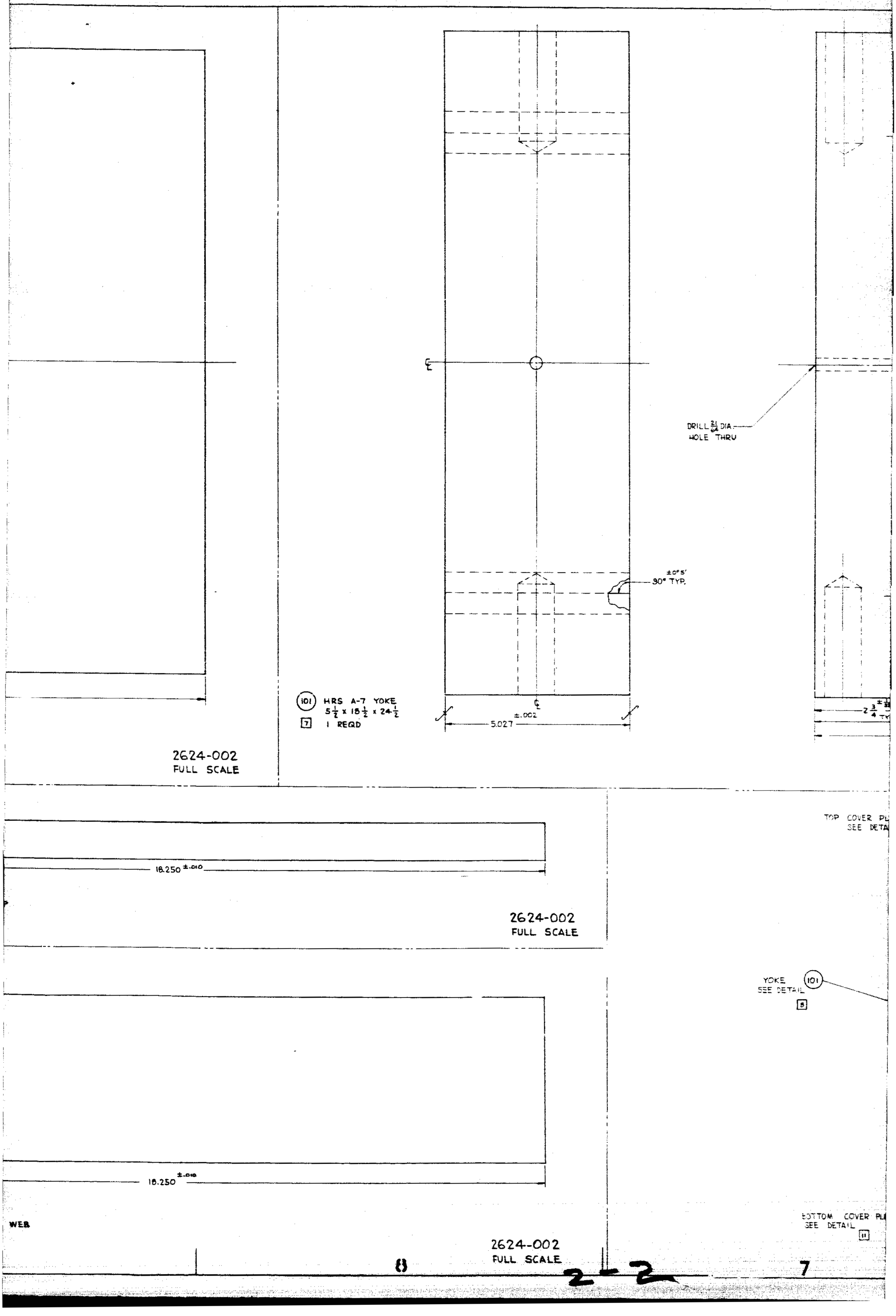
Packs E and F were identical to each other with a single exception. In Pack E, a sheet of titanium foil was placed under each cover plate; in Pack F, foil was placed only under the lower cover plate. The primary reason for the difference was to determine whether full exposure of steel to the nitric acid, as in Pack F, made the leaching process any easier. Subsequent results showed that the presence or absence of the titanium foil made no difference to the Chem-Mill supplier performing the leaching. Presence of the foil did make removal of the cover plates an easy operation, which, in turn, reduced leaching time by reducing the volume of steel to be dissolved. Consequently, two sheets of foil were designed into the full-scale Phase III packs.

To further ensure cleanness of the steel filler bars in Packs E and F, each bar was immediately solvent wiped after grinding and dimensional inspection, then wrapped securely in VPI (vapor phase inhibitor) paper and, as an outer protection, sealed in a clear plastic envelope as shown in figures 2 and 3.

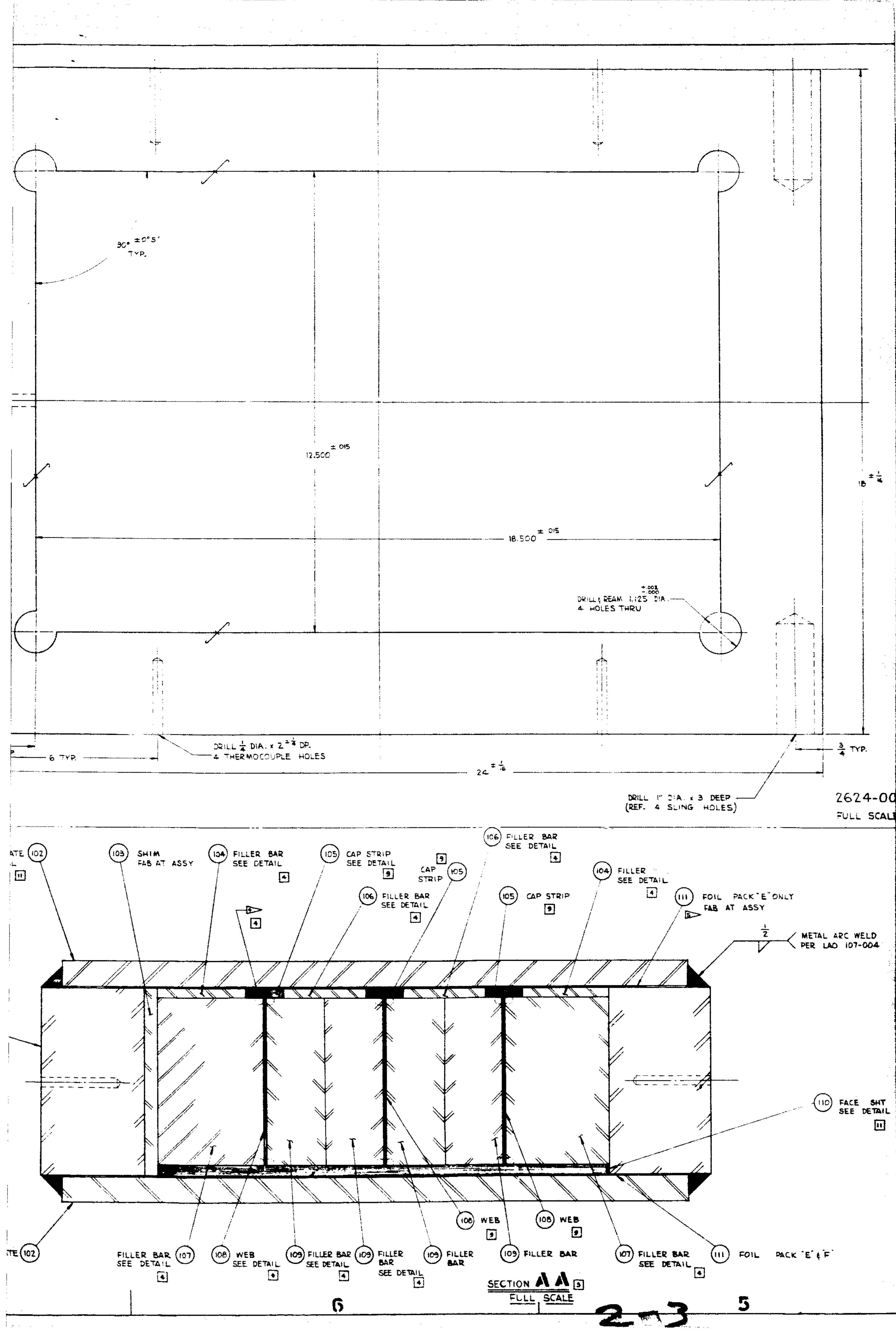
When unwrapped for layup, each steel filler bar had clean shiny surfaces with absolutely no trace of discoloration or contamination. (See figures 4 and 5.) Just prior to layup, the bars were hand-filed and polished to produce the 1/32-inch corner radii, which were inspected by radius gage. They were then solvent wiped and placed in position in the yoke.

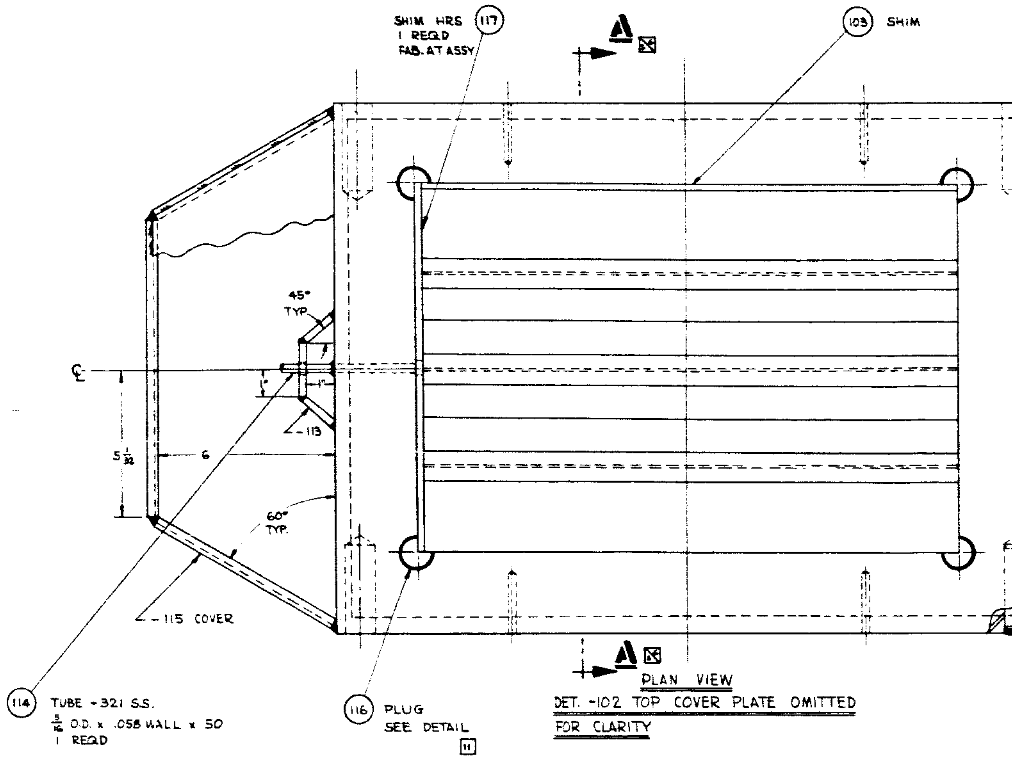
As with all roll diffusion bonding packs, E and F were assembled in the clean room with "white-glove" handling to ensure maximum cleanness. Welding, leak checking, and hot purging procedures were the same as those followed in the preparation of the first four packs. Both packs were stamped to make sure that they would be rolled with the face sheet down.

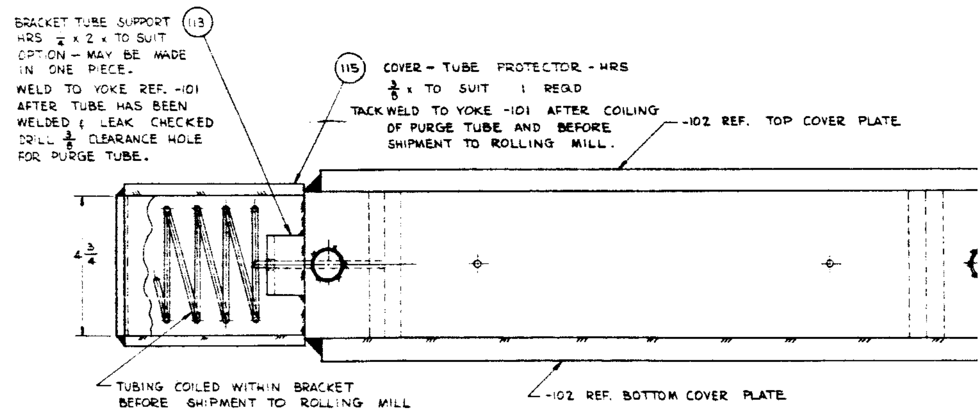

16 7/8 ±1/16
.737 ±.010
22 7/8 ±1/16
(102) HRS A7 COVER PLATE
7/8 x 17 x 23 2 REQD
6
.275 ±.002
18.250 ±.010
12.174 ±.010
(110) 6-1-1 TITANIUM ALLOY (MILL ANNEALED) FACE SHT
5/16 x 12 1/4 x 18 3/8 REQD
2624-002
1.000 ±.005
.250 ±.002
(105) 6-1-1 TITANIUM ALLOY (MILL ANNEALED) CAP STR
.250 x 1 1/8 x 18 3/8
3 REQD
4.500 ±.005
.060 ±.002
(108) 6-1-1 TITANIUM ALLOY (MILL ANNEALED)
.060 x 4 5/8 x 18 3/8
3 REQD
.560
90° ±0°15'
5.010 ±.010
.560 +.000 -.010
1/16 x 45°
(116) C-1018 OR C-1020 CFS PLUG
1 1/8 DIA. x 5 1/8 LG.
4 REQD
2624-002
FULL SCALE
1" DIA.
2 7/8
BREAK SHARP EDGES
(112) CRS PLUG
1" DIA x 3 4 REQD
2624-002
FULL SCALE
11
10
9

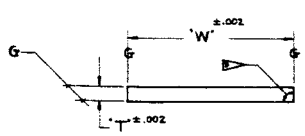


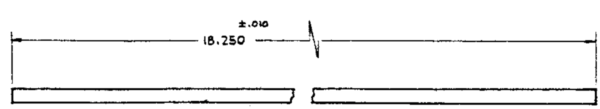
2624-002
FULL SCALE
101 HRS A-7 YOKE
5 1/2 x 18 1/2 x 24 1/2
7 1 REQD
±.002
5.027
±0°5'
90° TYP.
DRILL 21/64 DIA
HOLE THRU
18.250 ±.010
2624-002
FULL SCALE
TOP COVER
YOKE 101
SEE DETAIL
8
18.250 ±.010
WEB
BOTTOM COVER
SEE DETAIL
11
2624-002
FULL SCALE
8
2-2
7


30° ±0°5' TYP.
12.500 ±.015
18.500 ±.015
18 ±1/16
DRILL & REAM 1.125 DIA. 4 HOLES THRU
DRILL 1/4 DIA. x 2 ±1/4 DP. 4 THERMOCOUPLE HOLES
6 TYP.
24 ±1/16
3/4 TYP.
DRILL 1" DIA. x 3 DEEP (REF. 4 SLING HOLES)
2624-00
FULL SCAL
102
103 SHIM FAB AT ASSY
104 FILLER BAR SEE DETAIL 4
105 CAP STRIP SEE DETAIL 9
CAP STRIP 105
106 FILLER BAR SEE DETAIL 4
106 FILLER BAR SEE DETAIL 4
105 CAP STRIP 9
104 FILLER SEE DETAIL 4
111 FOIL PACK "E" ONLY FAB AT ASSY
METAL ARC WELD PER LAO 107-004
110 FACE SHT SEE DETAIL 11
108 WEB 9
108 WEB 9
102
FILLER BAR SEE DETAIL 4 107
108 WEB SEE DETAIL 4
109 FILLER BAR SEE DETAIL 4
109 FILLER BAR SEE DETAIL 4
109 FILLER BAR
109 FILLER BAR
107 FILLER BAR SEE DETAIL 4
111 FOIL PACK "E" & "F"
SECTION A A 9
FULL SCALE
6
2-3
5









(104) (106) (107) (109) G1018 OR C-1020 COLD FINISH STEEL BAR

DET.	REQD	T	W
104	2	.245	2.348
106	2	.245	2.239
107	2	4.482	2.818
109	4	4.482	1.589

NOTE !

1. ALL CORNERS MUST BE 90° ±0°5'
2. $\frac{1}{32}\,{}^{+\frac{1}{64}}_{-0}$ RADIUS ON ALL FILLER BARS AT CORNERS CODED THUS ◌ SEE SECTION AA 2

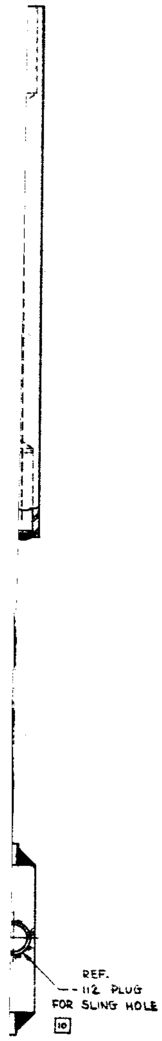
2624
PACK
SCALE

4 3

3-4

NA-66-57

REVISION				
LTR	ZONE	CHANGE	APP	DATE
E	5	OBS. SHT. # 1 OF 2 SHT. # 2 OF 2 ADDED FOR PACK "E" & "F" EXCEPT AS NOTED SEE CODE ▷ REF. DET. 111		11-24-65



GENERAL NOTES

1. MATERIAL OF PART - 8-1-1 TITANIUM ALLOY (MILL ANNEALED)
2. WELD PER STD. SHOP PRACTICE, EXCEPT AS NOTED.
3. DET'S -103 & -117 AS REQD AT TIME OF LAY UP. DRILL $\frac{3}{4}$ DIA. HOLE THRU -117 SHIM, LOC. AT ASSY.
4. FRACTIONAL TOL. $\pm\frac{1}{32}$, EXCEPT AS NOTED. DECIMAL TOL. $\pm$.010, EXCEPT AS NOTED.
5. PACK "E" & "F", EXCEPT AS NOTED ▷ 5 REF. DET. 111

-002
"E" & "F"
NONE

2

NORTH AMERICAN AVIATION, INC.
INTERNATIONAL AIRPORT
LOS ANGELES 45, CALIFORNIA

DATE 11-24-65

PACK ASSY - CONFIGURATION #2 S-IC ROLL DIFFUSION BOND TEST PANEL

2624-002

Figure 1. Design of Packs E and F

Figure 2. Protected Steel Filler Bars

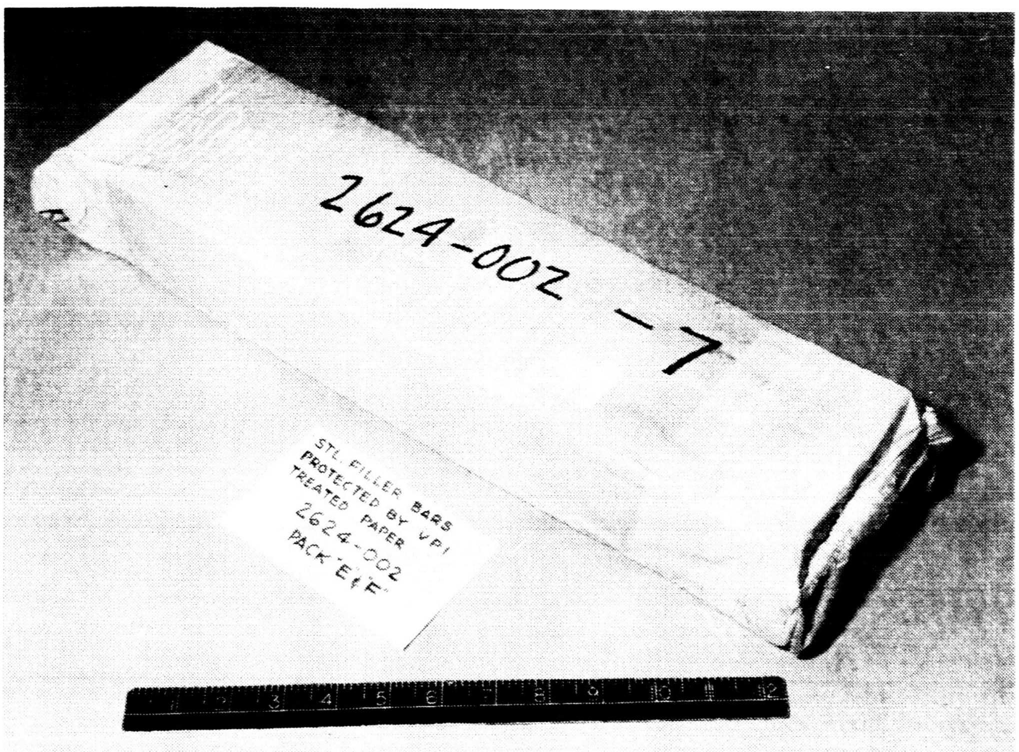


Figure 3. Steel Filler Bar Wrapped in VPI Paper

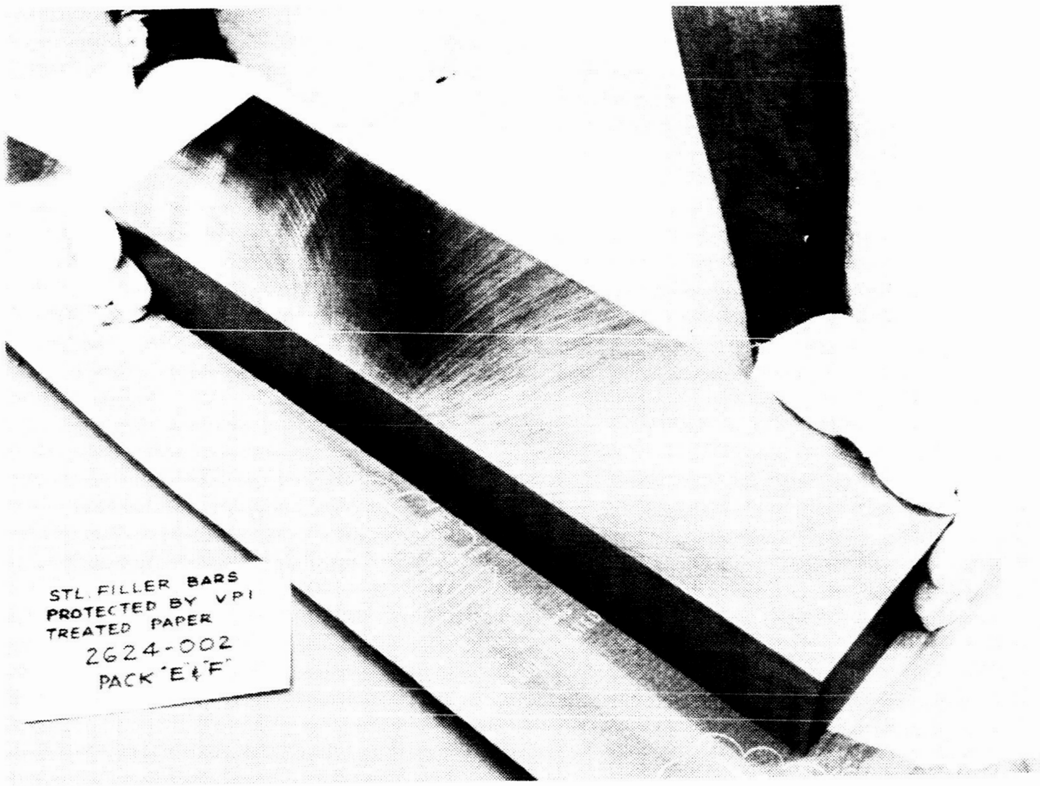


Figure 4. Unwrapping Filler Bar

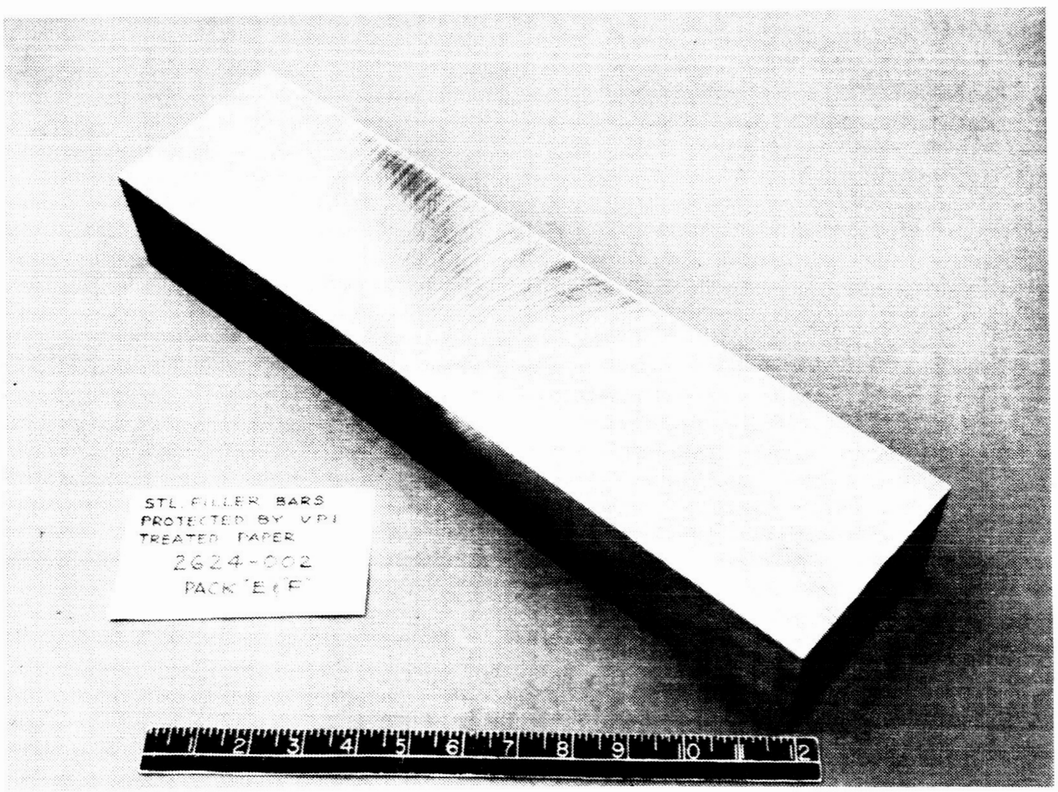


Figure 5. Filler Bar Ready for Layup

HOT ROLLING OPERATIONS

Hot rolling of Packs E and F was performed on 13 December 1965 at the U.S. Steel Applied Research Laboratory, Monroeville, Pennsylvania. Both packs were checked to ensure maintenance of vacuum, and the purge tubes were induction heated, hammered flat in the hot zone, and pinched off with a chisel.

The view of the laboratory equipment in figure 6 shows the three furnaces and the rolling mill. The opposite end of the mill is shown in figure 7, which highlights the water quench enclosure, the pressure rolls, and the control consoles. A closer view of the pressure rolls is shown in figure 8.

Pack E was charged into furnace No. 1 at 10:00 A.M., with a thermocouple inserted into the side of the yoke. By 2:00 P.M., the temperature had reached 1815°F and, following a soaking period of 1-1/2 hours, at which time the temperature recording was 1825°F, the pack was discharged from the furnace onto the conveyor rolls, as shown in figure 9. The steel plate which had been laid on the pack to minimize accumulation of scale on the cover plate surface was removed, and rolling operations began. This shielding has been provided on all test packs.

Pack F was charged into furnace No. 2 at 10:05 A.M. and was discharged onto the conveyor rolls at 3:56 P.M., with a recorded temperature of 1815°F.

Subsequent laboratory tests of the titanium panels at NAA/LAD indicated that improved bonding quality probably would have been obtained if the packs had been allowed to soak at 1825°F for a longer period to ensure complete penetration of heat uniformly throughout the assembly. A soak time of one hour for each inch of pack thickness is recommended by NAA and U.S. Steel personnel.

The hot rolling data for Pack E is presented in figure 10. After rolling, the pack was flattened in the laboratory's forging press and then put through a water quench cycle. Water spray was applied intermittently in three 2-minute periods separated by intervals of 45 seconds. Water flow rate was 80 gallons per minute, top spray pressure was 10 psig, and bottom spray pressure was 12 psig. An optical pyrometer reading just prior to the first quenching spray indicated the pack temperature to be 1400°F.

When, after quenching, the pack was placed on firebricks on the floor to air-cool to room temperature, it was noticed that there was a dome-like raised area, or bubble, in the center of the lower cover plate. This slightly raised circle, about 8 inches in diameter, was unique to Pack E. No such occurrence took place on any of the other five test packs in Phase I.

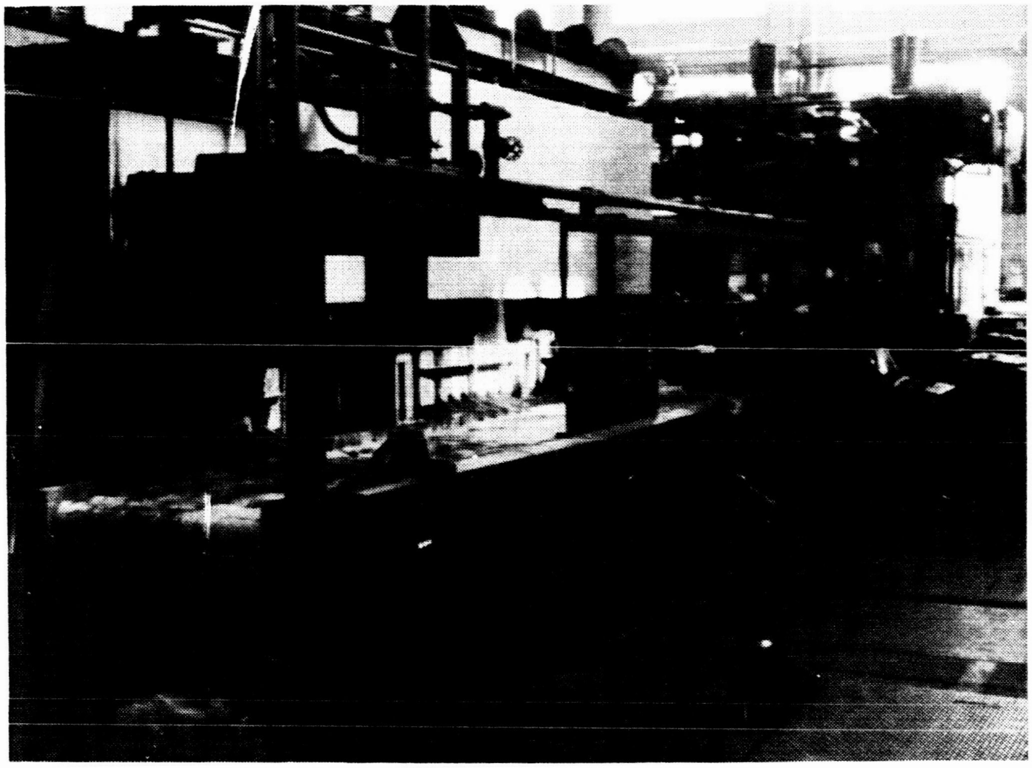


Figure 6. U.S. Steel Laboratory Rolling Mill and Furnaces

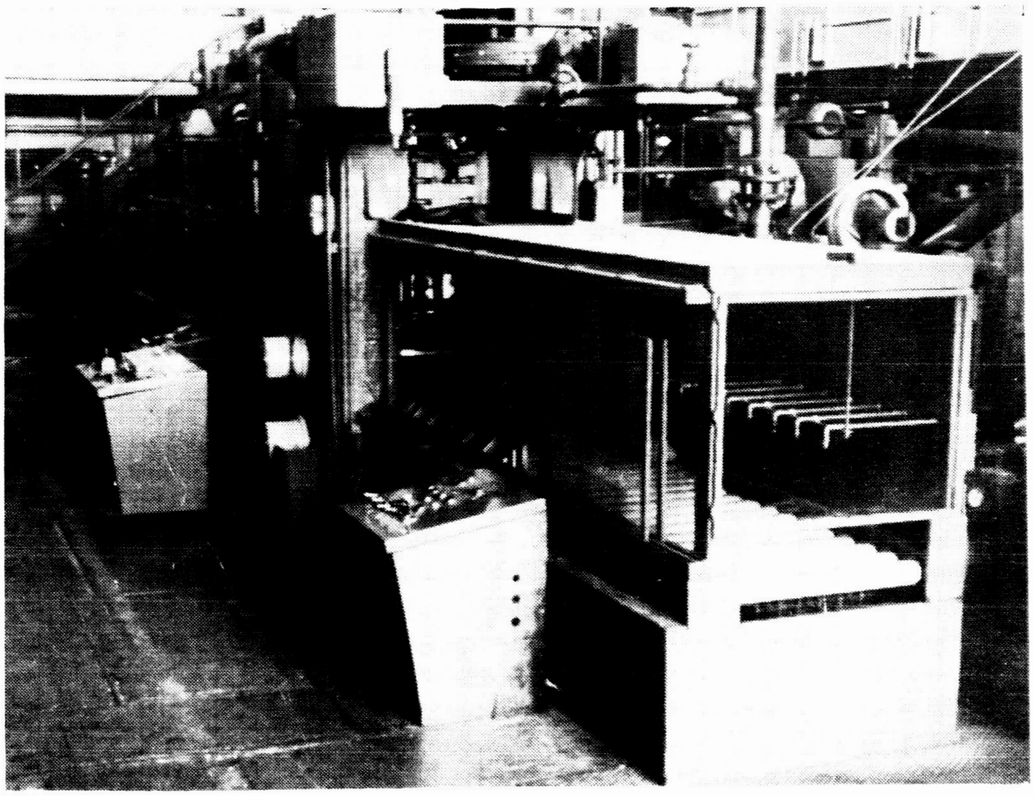


Figure 7. Rolling Mill, Showing Control Consoles and Water Quench Enclosure

Figure 8. Close-Up View of Rollers

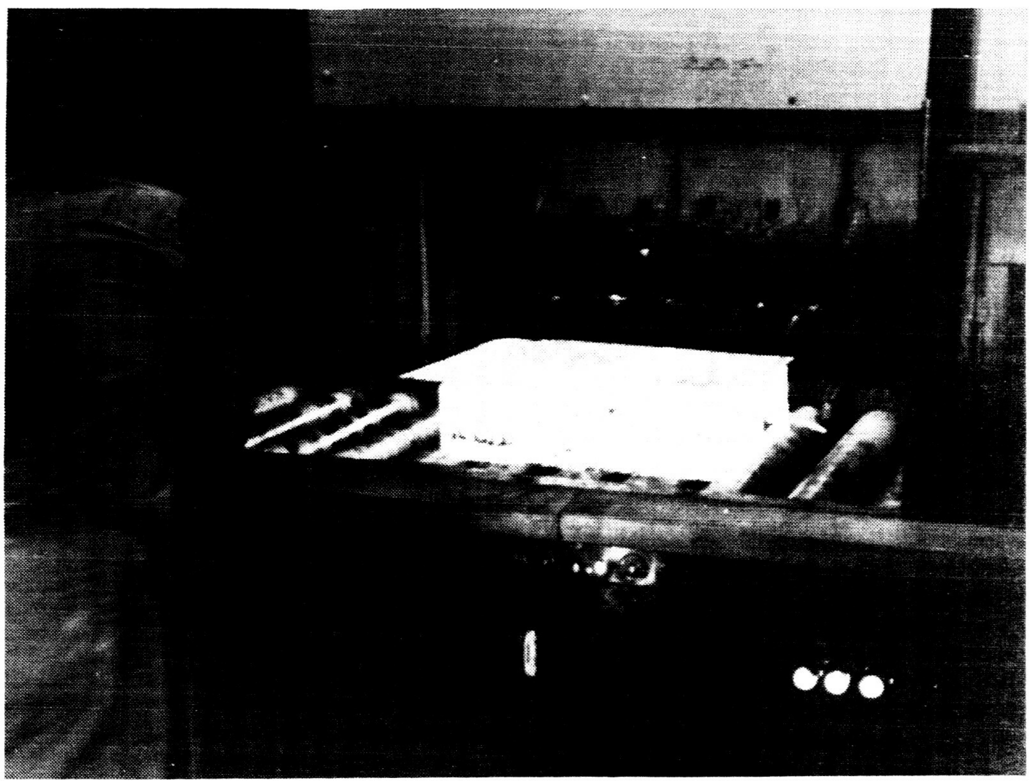


Figure 9. Heated Pack Discharged From Furnace

PASS NO.	TIME FROM FURNACE TO PASS, MIN: SEC	THICKNESS AFTER PASS, IN. (APPROX)	MILL OPENING, IN.	REDUCTION, IN.	REDUCTION, %	ROLLING SPEED, FPM	ROLLING HORSEPOWER	PEAK SEPARATING FORCE, LB	NORMAL SEPARATING FORCE, LB	NORMAL ROLLING PRESSURE, PSI
PACK E:										
1	0:15	6.120	6.030	0.317	4.9	104	330	600,000	588,000	18,800
2	0:23	5.660	5.550	0.460	7.5	88	490	756,000	753,000	19,400
3	0:33	5.220	5.110	0.440	7.8	89	380	769,000	738,000	19,400
4	0:41	4.810	4.700	0.410	7.8	91	485	769,000	763,000	20,800
5	0:51	4.420	4.320	0.390	8.1	93	380	706,000	672,000	18,900
6	0:59	4.070	3.970	0.350	7.9	96	480	722,000	713.000	21,100
7	1:08	3.750	3.650	0.320	7.9	96	360	666,000	619,000	19,200
8	1:16	3.460	3.360	0.290	7.7	100	455	669,000	656,000	21,300
9	1:25	3.190	3.100	0.270	7.8	100	360	609,000	550,000	18,500
10	1:33	2.980	2.890	0.210	6.6	109	390	588,000	575,000	21,900
11	1:41	2.800	2.720	0.180	6.0	111	320	509,000	453,000	18,900
12	1:49	2.670	2.590	0.130	4.6	117	290	450,000	447,000	21,700
13	1:57	2.571	2.500	0.099	3.7	119	220	394,000	372,000	20,700
PACK F:										
1	0:17	6.088	6.028	0.349	5.4	106	310	544,000	544,000	16,100
2	0:25	5.608	5.548	0.380	6.3	93	495	756,000	731,000	20,800
3	0:35	5.168	5.108	0.440	7.8	94	400	681,000	666,000	17,600
4	0:43	4.758	4.698	0.410	7.9	95	480	722,000	681,000	18,600
5	0:53	4.378	4.318	0.380	8.0	98	390	625,000	603,000	17,100
6	1:01	4.028	3.968	0.350	8.0	100	460	684,000	641,000	19,000
7	1:11	3.708	3.648	0.320	8.0	100	360	588.000	547.000	17,000
8	1:19	3.418	3.358	0.290	7.8	102	435	641,000	594,000	19,300
9	1:28	3.158	3.098	0.260	7.6	104	360	534,000	494,000	16,900
10	1:36	2.948	2.888	0.210	6.7	112	365	556,000	522,000	19,900
11	1:46	2.778	2.718	0.170	5.8	113	300	463,000	391,000	16,600
12	1:53	2.648	2.588	0.130	6.7	119	275	453,000	397,000	19,300
13	2:02	2.556	2.498	0.092	1.4	120	205	365,000	342,000	19,800

Figure 10. Hot Rolling Data for Packs E and F

Rolling data for Pack F is presented in figure 10. After the postrolling flattening operation, the pack was placed on firebricks on the floor and allowed to air cool.

Measurements of both packs were made on December 14 and are shown in figure 11. The fact that, in cross section, the center is thinner than the outer edges is attributable to the plasticity of the titanium at 1800°F as compared to the low carbon steel, which constituted the solid mass of the yoke sides. Also, there is more springback in the solid steel sides than in the titanium-steel center.

POSTROLLING OPERATIONS

Upon their return to NAA/LAD, both packs were flame cut with an oxyacetylene torch in the same manner as previous packs to remove the yokes, and cover plates were removed.

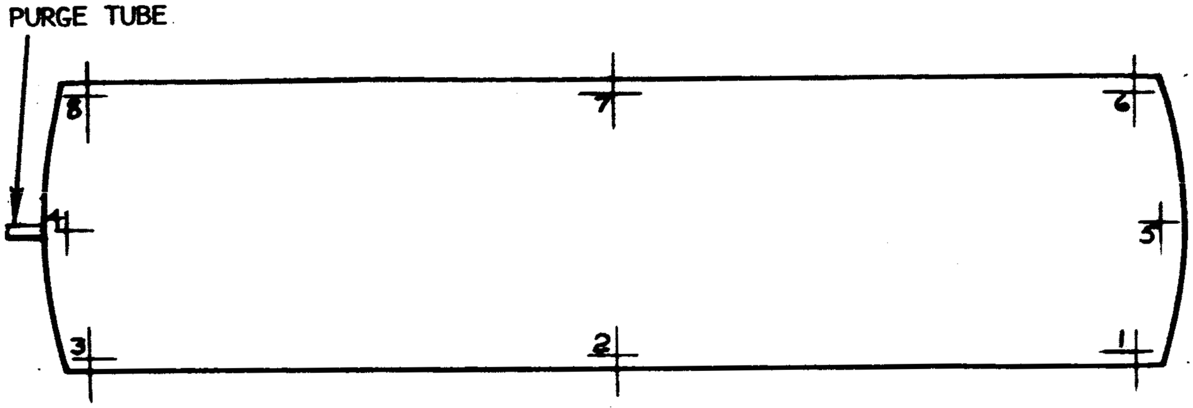
Both packs were delivered to an outside supplier for leaching to remove the steel. The titanium panels were returned to LAD for cleaning per NAA Process Specification LA0110-008. Final rinse was in deionized water, followed by oven drying.

As shown in figure 12, both panels had a good appearance and the bond joints looked good, except for the end-trim areas which, as in previous panels, showed lack of bond. This condition is shown in figure 13 in the web-to-cap joint. The web-to-face sheet joint, as seen in figure 14, does not indicate a lack of bond.

These three illustrations give clear evidence that, in the hot rolling operations, the upper part of the pack is elongated to a greater extent than the lower zone. One reason for this may be that the conveyor rolls chill the underside of the packs. It is thought that the differential in growth causes an unequal separation within the pack along the line of demarcation between the inside face of the yoke and the ends of the steel and titanium components. A resultant void in the lower part of the pack could mean the absence of support under the upper portion during rolling, causing the lack of bond.

Warpage caused by water quenching of Pack E is evident in the end view of the titanium panel from that pack (figure 15). Comparative flatness of air-cooled Pack F is shown in figure 16.

Both panels were inspected by penetrant and Penestrip methods and, except for the unbonded areas at both ends of each pane, no cracks were discovered in the bond joints nor in the surfaces. Later developments led to the conclusion that neither penetrant inspection nor the Penestrip technique was a reliable method for assuring diffusion bond quality.



PACK AFTER ROLLING
THICKNESS MEASUREMENTS TAKEN APPROXIMATELY ONE INCH FROM EDGE
WIDTH: PACK E - 18-3/8; PACK F - 18-3/4
LENGTH: PACK E - 58-3/4; PACK F - 59-1/4

LOCATION	PACK E	PACK F
1	2.577	2.560
2	2.579	2.557
3	2.577	2.560
4	2.550	2.543
5	2.563	2.540
6	2.575	2.567
7	2.574	2.560
8	2.577	2.563
AVERAGE	2.571	2.556

Figure 11. Pack Dimensions After Rolling

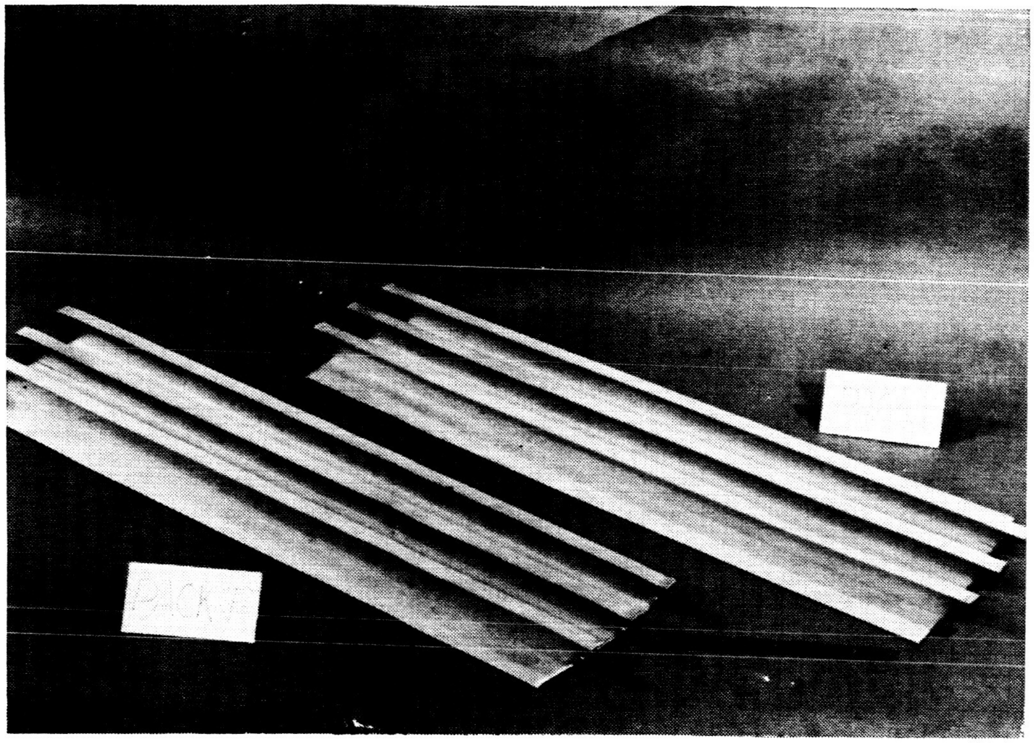


Figure 12. Test Panels E and F

Figure 13. Warpage in Panel E Attributed to Quenching

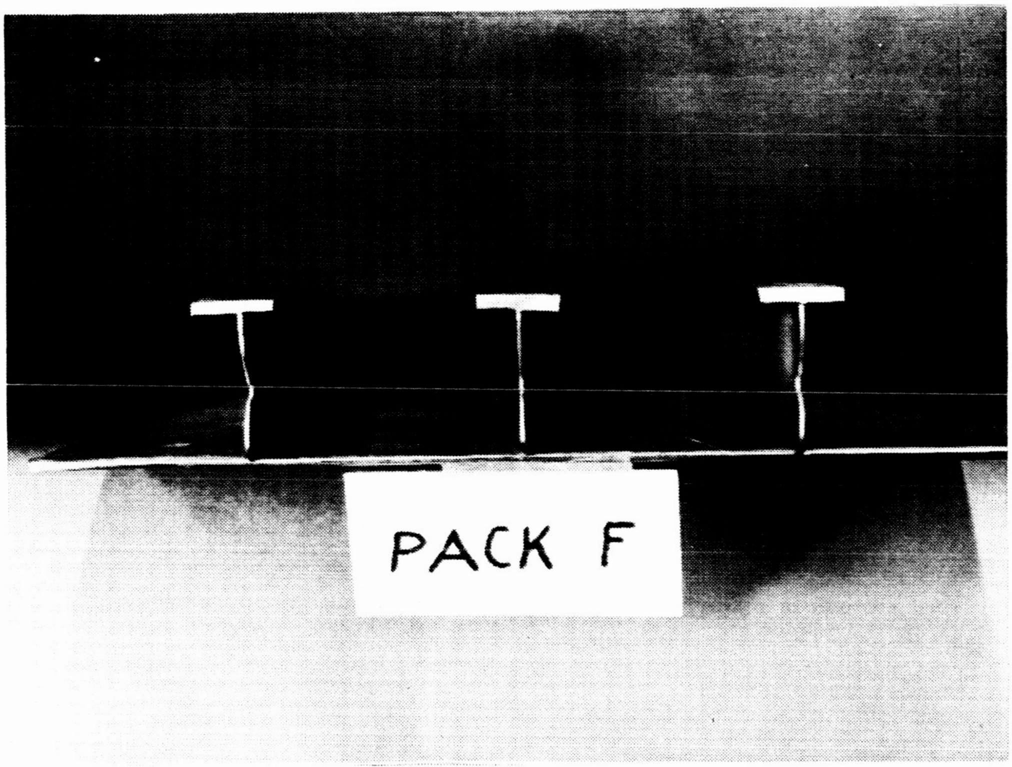


Figure 14. Flatness of Air-cooled Panel F

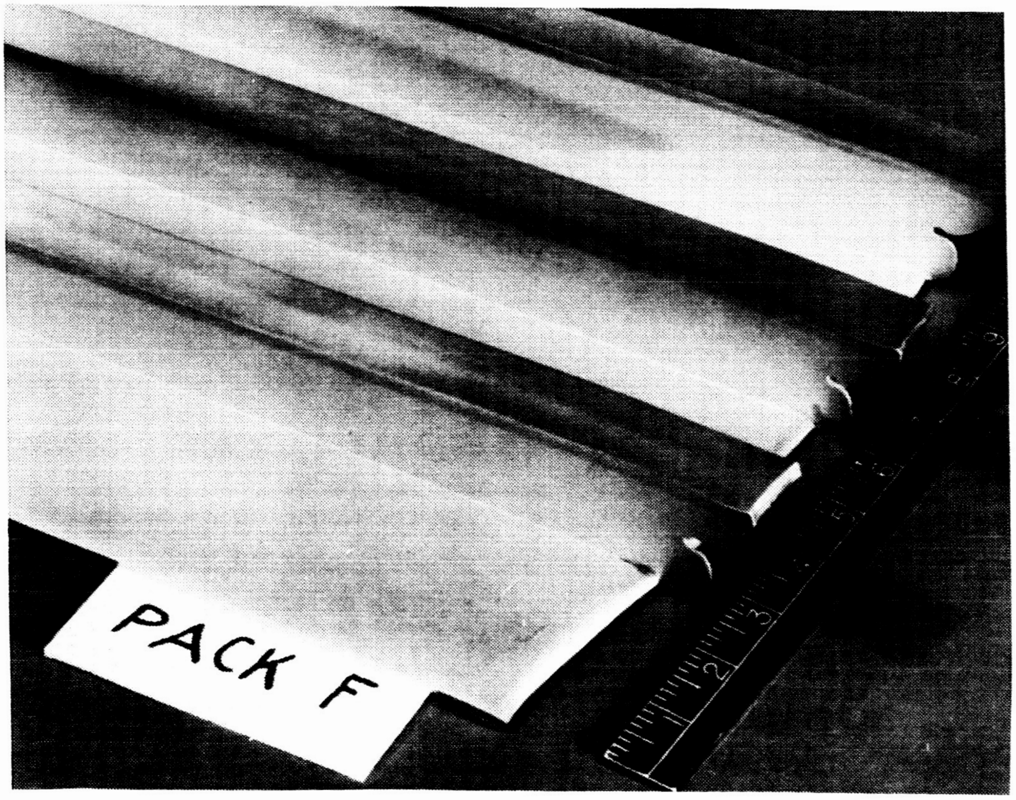


Figure 15. Good Appearance of Web-to-Face Sheet Bond in Panel F

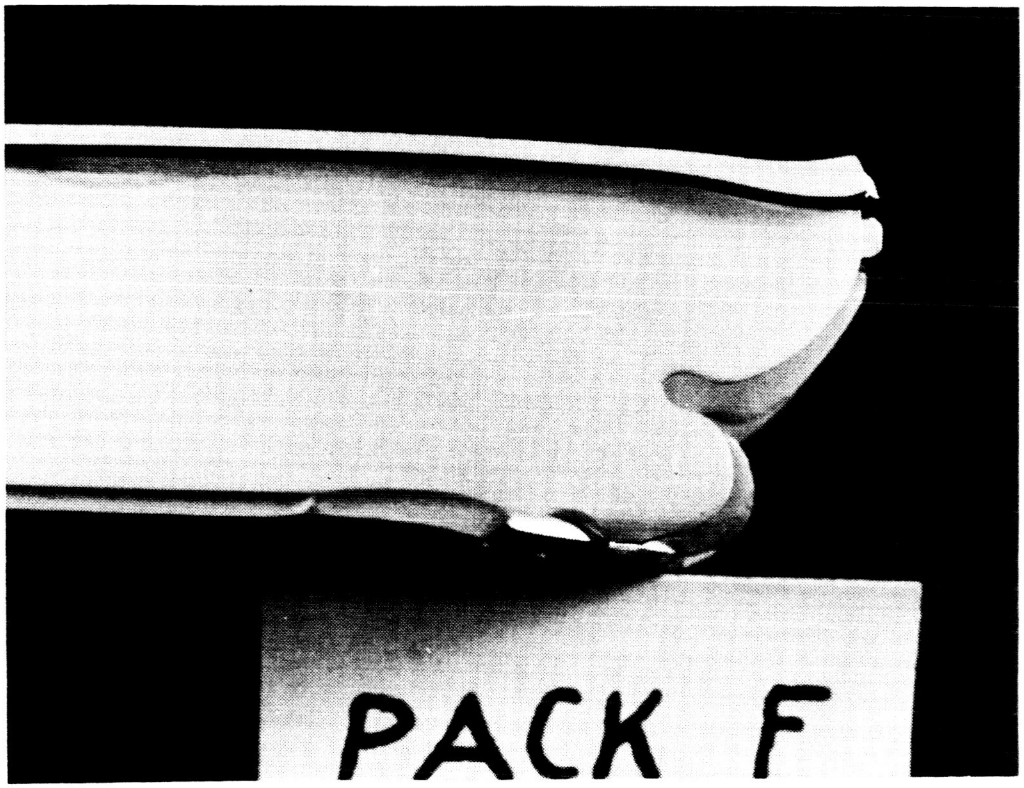
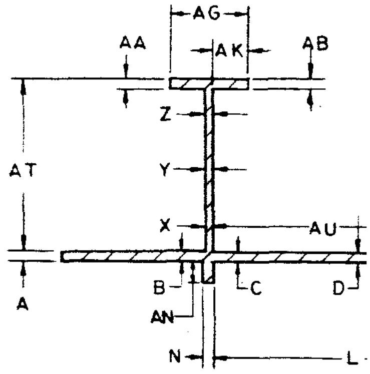


Figure 16. Close View of Lack of Bond, Web-to-Cap Strip, in Trim Area of Panel F



FACE SHEET THICKNESS MAX. .103

	STA.	A	B	C	D
TARGET DIM. .100 ±.002	I	.103	.099	.100	.098
	II	.098	.096	.096	.098
	III	.099	.097	.100	.099
	IV	.101	.097	.100	.101
	V	.096	.091	.094	.094

STRINGER THICKNESS MAX. .112 MIN. .

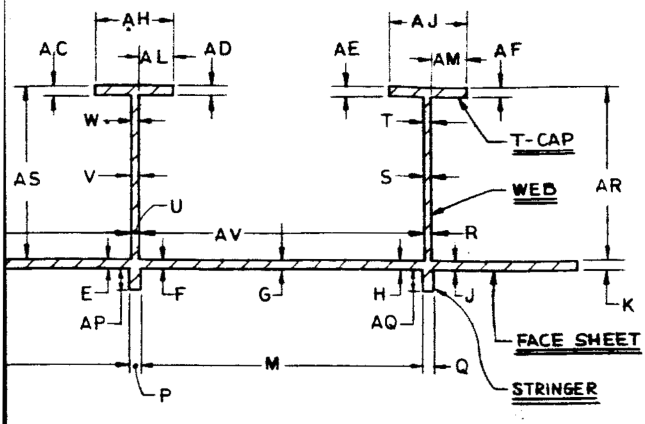
	STA.	N	P	Q	
TARGET DIM. .100 ±.002	I	.099	.099	.102	
	II	.099	.099	.098	
	III	.101	.098	.102	
	IV	.101	.098	.105	
	V	.102	.096	.108	

STRINGER HEIGHT MAX. .205 MIN.

	STA.	AN	AP	AQ	
TARGET DIM. .100 ±.002	I	.203	.205	.204	
	II	.196	.196	.197	
	III	.200	.199	.199	
	IV	.204	.204	.203	
	V	.194	.194	.196	

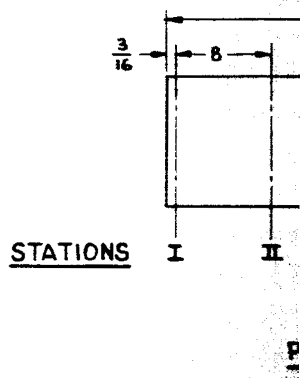
WEB THICKNESS MAX. .066 MIN. .

	STA.	R	S	T	U
TARGET DIM. .062 ±.002	I	.064	.063	.062	.061
	II	.062	.062	.062	.061
	III	.063	.062	.061	.062
	IV	.062	.061	.061	.061
	V	.061	.061	.060	.062



SECTION AA

Rotated 90° Counterclockwise



MIN. .091 AVG. .097 DEVIATION ± .006 / .006

E	F	G	H	J	K	
.098	.098	.098	.098	.096	.100	
.098	.098	.098	.099	.092	.097	
.098	.100	.099	.099	.091	.097	
.099	.099	.099	.098	.094	.100	
.095	.094	.094	.095	.094	.095	

04 AVG. .108 DEVIATION ±.004

.194 AVG. .199 DEVIATION ± .006 / .005

060 AVG. .062 DEVIATION ± .004 / .002

V	W	X	Y	Z	
.063	.065	.065	.066	.062	
.061	.063	.064	.064	.061	
.062	.062	.064	.062	.062	
.061	.063	.064	.063	.062	
.060	.062	.065	.065	.061	

T-HEIGHT MAX. 1.926 MIN. 1.900 AVG. 1.911

	STA.	AR	AS	AT	
TARGET DIM. 1.900	I	1.902	1.903	1.900	
	II	1.912	1.910	1.910	
	III	1.915	1.909	1.912	
	IV	1.904	1.907	1.902	
	V	1.926	1.925	1.926	

T-CAP THICKNESS MAX. .113 MIN. .098 AVG. .1

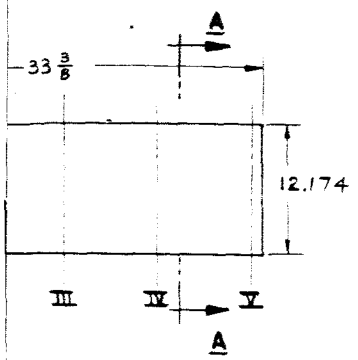
	STA.	AA	AB	AC	AD
TARGET DIM. .100 ±.002	I	.100	.102	.107	.106
	II	.106	.108	.110	.110
	III	.106	.108	.111	.109
	IV	.103	.104	.106	.106
	V	.098	.098	.103	.102

T-CAP WIDTH MAX. .809 MIN. .783 AVG. .795 DI

	STA.	AG	AH	AJ
TARGET DIM. .812 ±.010	I	.804	.796	.787
	II	.800	.796	.787
	III	.804	.796	.784
	IV	.809	.796	.787
	V	.803	.790	.783

STRINGER SPACING MAX. 3.037 MIN. 2.975 A

	STA.	L	M
TARGET DIM. 2.962	I	3.007	3.023
	II	3.012	3.029
	III	3.014	3.037
	IV	3.010	3.035
	V	2.975	2.982



LAN VIEW OF PANEL

NOTE: ALL DIMENSIONS TO THE NEAREST .001

EVIATION ± .015 / .011

T-SPACING MAX. 3.112 MIN. 3.033 AVG. 3.089 DEVIATION ± .023 / .056

TARGET DIM. 3.000 ±.010

STA.	AU	AV
I	3.094	3.095
II	3.105	3.110
III	3.108	3.112
IV	3.095	3.104
V	3.033	3.033

6 DEV. ± .007 / .004

AE	AF
.109	.110
.111	.111
.112	.113
.108	.109
.103	.103

T-CAP ALIGN. WITH WEB MAX. .380 MIN. .356 AVG. .365 DEV. ± .015 / .009

TARGET DIM. .375 ±.010

STA.	AK	AL	AM
I	.369	.368	.359
II	.370	.360	.360
III	.370	.360	.356
IV	.380	.362	.358
V	.366	.365	.368

V. ± .014 / .012

DIMENSIONS TAKEN AFTER PICKLE ONLY WHICH REMOVES .0005 MAX. FROM ALL SURFACES.

PACK "A"

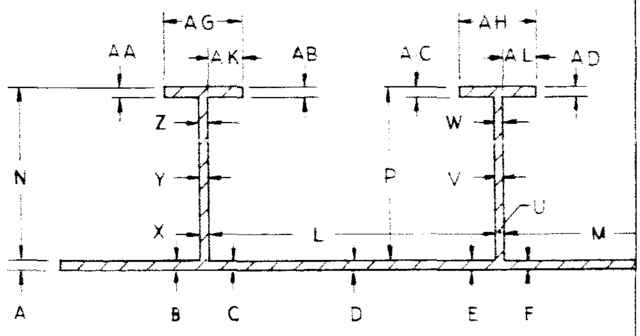
G. 3.012 DEV. ± .025 / .037

INSP.
10-19-65
J.E. GARY

DIMENSIONS TRANSFERRED FROM ORIG. INSP. BLUELINE.

SCALE: —	DR. Y. MORIWAKI / DATE 11-1-1965 / MODEL	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA	
DIMENSIONAL ANALYSIS OF 2624-001 CONFIG.# I S-IC TITANIUM ROLL DIFFUSION BOND - PACK ASSY			2624-008

Figure 17. Dimensional Analysis of Panel



SECTION A

Rotated 90° Counterclockw

FACE SHEET THICKNESS MAX. .102 MIN. .095 AVG. .

TARGET DIM. .100 ± .002

STA.	A	B	C	D	E	F	G
I	.100	.102	.097	.098	.096	.099	.098
II	.101	.100	.098	.098	.096	.100	.099
III	.099	.099	.096	.097	.095	.099	.097
IV	.101	.100	.099	.099	.097	.100	.100
V	.101	.100	.100	.100	.096	.100	.100

WEB THICKNESS MAX. .069 MIN. .061 AVG. .0648

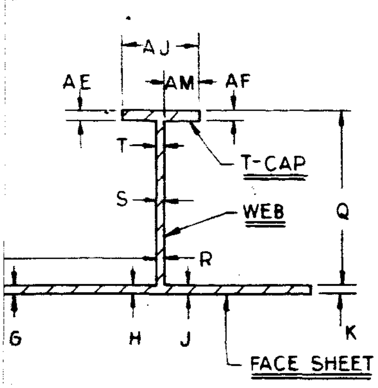
TARGET DIM. .062 ± .002

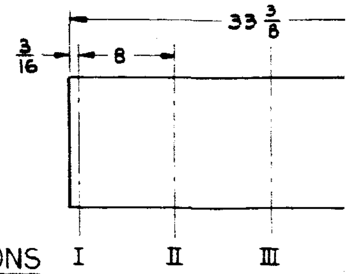
STA.	R	S	T	U	V	W	X
I	.067	.066	.066	.065	.062	.062	.065
II	.064	.064	.066	.065	.062	.062	.069
III	.065	.065	.066	.066	.063	.063	.068
IV	.065	.064	.065	.064	.064	.063	.067
V	.064	.062	.066	.064	.061	.062	.065

T-CAP WIDTH MAX. .801 MIN. .780 AVG. .793 DEV. ± .008 / .013

TARGET DIM. .812 ± .010

STA	AG	AH	AJ
I	.788	.780	.784
II	.797	.794	.791
III	.800	.796	.791
IV	.801	.796	.792
V	.801	.790	.789





PLAN VIE

A

vise

0986 DEVIATION ± .0034 .0036

	H	J	K
	.100	.098	.101
	.099	.098	.101
	.098	.097	.099
	.101	.098	.100
	.100	.099	.102

T-HEIGHT MAX. 1.907 MIN. 1.884 AVG. 1.896 DEVIATION ±

TARGET DIM. 1.900

STA.	N	P	Q
I	1.892	1.898	1.896
II	1.891	1.900	1.899
III	1.897	1.904	1.907
IV	1.897	1.896	1.898
V	1.889	1.890	1.884

DEVIATION ± .0042 .0038

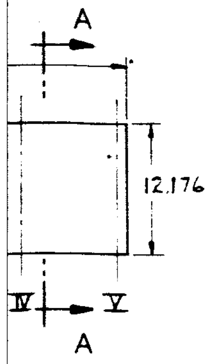
	Y	Z
	.066	.065
	.066	.067
	.066	.067
	.067	.066
	.066	.064

T-CAP THICKNESS MAX. .115 MIN. .106 AVG. .110 DEV. ±

TARGET DIM. .100 ±.002

STA.	AA	AB	AC	AD	AE	
I	.111	.110	.111	.111	.112	.1
II	.111	.111	.111	.110	.111	.1
III	.112	.112	.111	.111	.114	.1
IV	.109	.108	.109	.110	.111	.1
V	.107	.106	.107	.108	.109	.1

DIMENSIONS
FROM ORIG. IN



W OF PANEL

NOTE: ALL DIMENSIONS TO THE NEAREST .001

D11
D12

T-SPACING MAX. 3.108 MIN. 3.026 AVG. 3.072 DEVIATION ± .036 .046

TARGET DIM. 3.000 ±.010

STA.	L	M
I	3.026	3.036
II	3.077	3.098
III	3.085	3.108
IV	3.077	3.104
V	3.042	3.065

05
04

T-CAP ALIGN. WITH WEB MAX. .374 MIN. .360 AVG. .364 DEVIATION ± .010 .004

TARGET DIM. .375 ±.010

F	STA.	AK	AL	AM
2	I	.363	.360	.360
3	II	.370	.360	.360
5	III	.372	.362	.360
1	IV	.373	.363	.360
0	V	.374	.361	.362

PACK "B"

CONFIGURATION #1 WITH .200 STRINGERS REMOVED
DIMENSIONS TAKEN BEFORE GRIT BLASTING & PICKLE OPERATIONS WHICH REMOVE .002 FROM ALL SURFACES

SP.

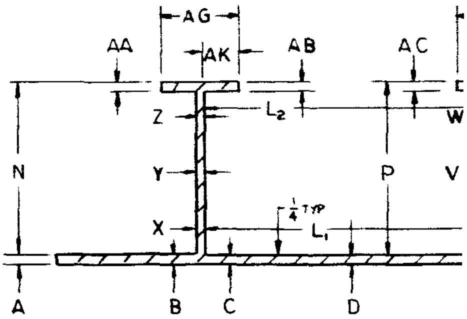
TRANSFERRED
P. BLUELINE.

SCALE:	DR. M. MORIWAKI	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
—	DATE 11-1-1965	
	MODEL	

DIMENSIONAL ANALYSIS OF 2624-001 CONFIG.#2
S-IC TITANIUM ROLL DIFFUSION BOND-PACK ASSY

2624-009 .3

Figure 18. Dimensional Analysis of Panel B

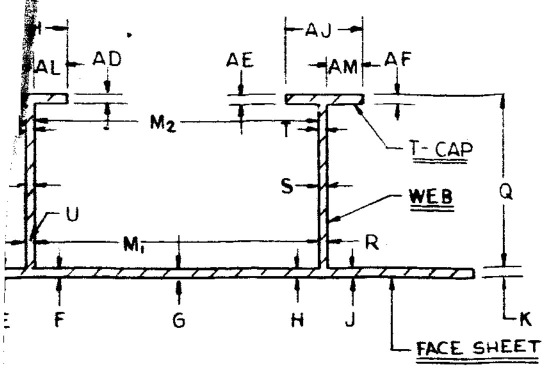


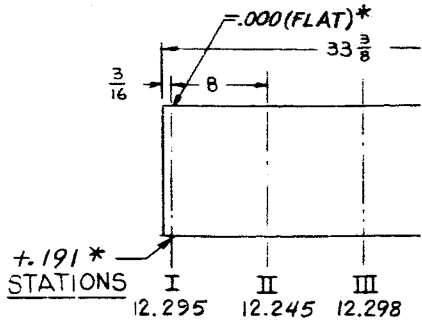
SE

Rotat

FACE SHEET THICKNESS MAX. .131 MIN. .						
	STA.	A	B	C	D	E
⊕ TARGET DIM. .110 ±.002	I	.120	.118	.115	.114	.115
	II	.124	.122	.120	.119	.120
	III	.131	.127	.125	.124	.124
	IV	.121	.120	.116	.118	.119
	V	.120	.120	.114	.114	.115

WEB THICKNESS MAX. .062 MIN. .059						
	STA	R	S	T	U	V
⊕ TARGET DIM. .062 ±.002	I	.061	.062	.062	.061	.061
	II	.061	.062	.062	.061	.062
	III	.061	.061	.062	.061	.062
	IV	.060	.061	.062	.061	.061
	V	.060	.061	.061	.060	.06[illegible]





PLAN VIE

CTION **A A**

PACK "E"

d 90° Counterclockwise

14 AVG. .119 DEVIATION $^{+.012}_{-.005}$

F	G	H	J	K
.115	.115	.114	.116	.116
.119	.118	.118	.121	.120
.124	.126	.125	126	.127
.116	.117	.117	.116	.116
.114	.114	.114	.115	.115

T-HEIGHT MAX. 1.904 MIN. 1.829 AVG. 1.870 DEVIATION

	STA.	N	P	Q
TARGET DIM. 1.900	I	1.856	1.887	1.837
	II	1.866	1.890	1.851
	III	1.868	1.885	1.872
	IV	1.879	1.901	1.859
	V	1.829	1.904	1.859

* PART IS TWISTED. THE VARIATION F FLATNESS OF FO POINTS IS CH IN PLAN VIEW. PART WAS RESTI ITS FACE SHEE IN A FREE STA WHEN DIM'S. WERE TAKEN F CHART.

AVG. .061 DEVIATION $^{+.001}_{-.002}$

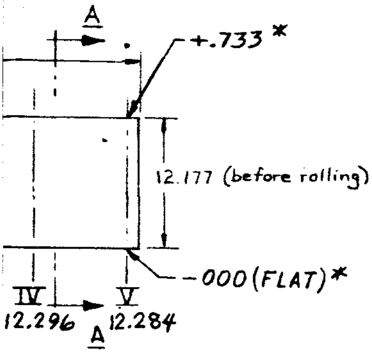
W	X	Y	Z
.062	.059	.060	.061
.062	.060	.060	.062
.062	.060	.060	.062
.062	.060	.060	.061
.062	.059	.060	.060

T-CAP THICKNESS MAX. .108 MIN. .093 AVG. .101 DEV. ±

	STA	AA	AB	AC	AD	AE
TARGET DIM. .100 ±.010	I	.108	.105	.104	.101	.099
	II	.105	.100	.100	.099	.097
	III	.102	.097	.095	.094	.093
	IV	.107	.104	.102	.100	.099
	V	.108	.107	.105	.103	.101

T-CAP WIDTH MAX. 1.010 MIN. .970 AVG. .991 DEV. $^{+.019}_{-.021}$

	STA	AG	AH	AJ
TARGET DIM. 1.000 ±.010	I	.985	.995	1.010
1-7-66	II	.980	.997	1.003
	III	.970	1.000	.997
	IV	.975	1.003	.994
	V	.977	.985	.992



V OF PANEL

NOTE: ALL DIMENSIONS TO THE NEAREST .001

$\pm^{.034}_{.041}$

OM R RTED G, ON T, E, OR

T-SPACING MAX. 3.313 MIN. 3.220 AVG. 3.260 DEVIATION $\pm^{.053}_{.040}$

	STA.	L_1	M_1	STA.	L_2	M_2
TARGET DIM. 3.178 ±.010 1-7-66	I	3.288	3.233	I	3.240	3.255
	II	3.253	3.248	II	3.278	3.313
	III	3.260	3.246	III	3.280	3.310
	IV	3.253	3.269	IV	3.270	3.297
	V	3.220	3.232	V	3.224	3.244

.07 .07

T-CAP ALIGN. WITH WEB MAX. .463 MIN. .458 AVG. .460 DEV. $\pm^{.003}_{.002}$

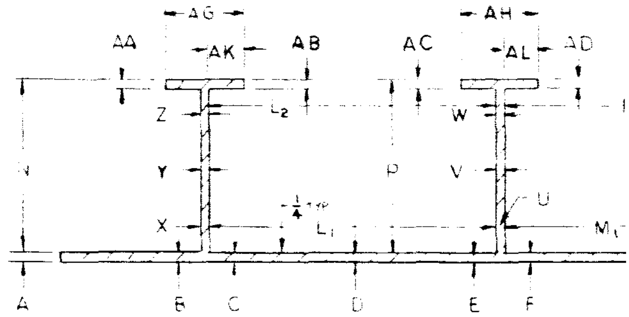
AF		STA	AK	AL	AM
.101	TARGET DIM. .469 ±.010 1-10-66	I	.458	.463	.463
.099		II	.463	.460	.458
.095		III	.458	.461	.458
.101		IV	.460	.462	.461
.104		V	.462	.460	.460

PACK "E"

SCALE: —	DR. L. BOWMAN DATE 2-10-66 MODEL	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
DIMENSIONAL ANALYSIS OF 2624-002 S-IC TITANIUM ROLL DIFFUSION BOND-PACK ASSY		2624-010

Figure 19. Dimensional Analysis of Panel E

3



SECTION A

PACK "F"

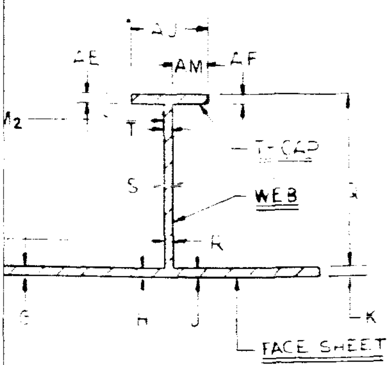
Rotated 90° counterclockw

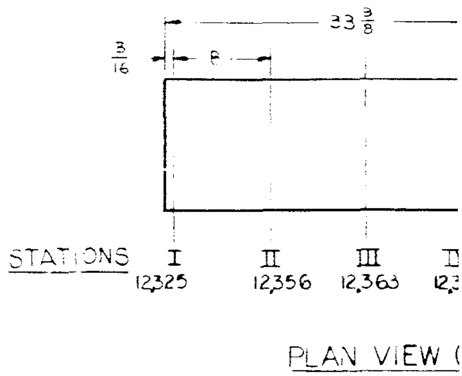
FACE SHEET THICKNESS MAX. .126 MIN. .110 AVG.

TARGET DIM. .110 ±.002	STA.	A	B	C	D	E	F	G
	I	.116	.115	.110	—	.113	.112	—
	II	.119	.116	.116	—	.116	.115	—
	III	.119	.119	.117	—	.118	.117	—
	IV	.121	.121	.118	—	.116	.116	—
	V	.119	.117	.114	—	.114	.115	—

WEB THICKNESS MAX. .065 MIN. .062 AVG. .064

TARGET DIM. .062 ±.002	STA	R	S	T	U	V	W	X
	I	.063	.063	.063	.064	.064	.064	.06
	II	.063	.063	.064	.064	.064	.063	.06
	III	.064	.064	.064	.064	.064	.064	.06
	IV	.063	.063	.065	.065	.064	.065	.06
	V	.062	.064	.065	.063	.063	.062	.06





A

ise

.117 DEVIATION $\pm^{.009}_{.007}$

G	H	J	K	
—	.111	.115	.120	OUTER SURFACE OF FACE SHEET HAD BEEN HAND GROUND BY MISTAKE AT CHEM-MILL SUPPLIER. SCORED FULL LENGTH OF PANEL AT POINTS D AND G. THICKNESS MEASUREMENT NOT POSSIBLE IN THESE AREAS.
—	.115	.112	.122	
—	.118	.121	.126	
—	.114	.119	.125	
—	.114	.115	.121	

DEVIATION $\pm^{.001}_{.002}$

X	Y	Z
3	.064	.063
3	.064	.065
4	.064	.064
4	.065	.065
2	.064	.064

T-HEIGHT MAX. 1.886 MIN. 1.865 AVG. 1.876 DEVIATION ±

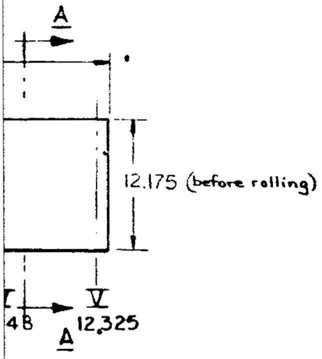
	STA.	N	P	Q
TARGET DIM. 1.900	I	1.886	1.884	1.870
	II	1.879	1.884	1.870
	III	1.872	1.875	1.865
	IV	1.879	1.880	1.867
	V	1.878	1.879	1.869

T-CAP THICKNESS MAX. .105 MIN. .094 AVG. .099 DEV. $\pm^{.006}_{.005}$

	STA	AA	AB	AC	AD	AE	A
TARGET DIM. .100 ±.010	I	.101	.098	.100	.100	.101	.10
	II	.101	.096	.097	.098	.099	.10
	III	.099	.094	.094	.095	.096	.10
	IV	.099	.095	.095	.096	.098	.10
	V	.101	.098	.099	.100	.099	.10

T-CAP WIDTH MAX. 1.020 MIN. .997 AVG. 1.007 DEV. $\pm^{.013}_{.010}$

	STA	AG	AH	AJ
TARGET DIM. 1.000 ±.010	I	1.010	1.002	.997
1-7-66	II	1.015	1.020	1.001
	III	1.013	1.017	1.000
	IV	1.015	1.013	.998
	V	1.006	1.000	.998



DF PANEL

NOTE ALL DIMENSIONS TO THE NEAREST .001

T-SPACING MAX. 3.308 MIN. 3.221 AVG 3.268 DEVIATION $\pm^{.040}_{.047}$

	STA.	L_1	M_1		STA.	L_2	M_2
TARGET DIM. 3.178 ±.010 1-7-66	I	3.225	3.232	NOTE: ALL "L & M" DIMS. ARE TAKEN AT THE BASE OF THE LEGS.	I	3.256	3.268
	II	3.262	3.260		II	3.298	3.306
	III	3.270	3.267		III	3.308	3.307
	IV	3.266	3.263		IV	3.293	3.300
	V	3.227	3.221		V	3.258	3.267

T-CAP ALIGN. WITH WEB MAX. .474 MIN. .326 AVG. .421 DEV. $\pm^{.053}_{.095}$

	STA	AK	AL	AM
TARGET DIM. .469 ±.010 1-10-66	I	.343	.466	.471
	II	.340	.474	.454
	III	.346	.469	.454
	IV	.337	.463	.454
	V	.326	.449	.462

PACK "F"

SCALE:	DR. L. BOWMAN	NORTH AMERICAN AVIATION, INC. INTERNATIONAL AIRPORT LOS ANGELES 45, CALIFORNIA
	DATE 2-10-66	
	MODEL	

DIMENSIONAL ANALYSIS OF 2624-002
S-IC TITANIUM ROLL DIFFUSION BOND-PACK ASSY

2624-011

3

Figure 20. Dimensional Analysis of Panel F

DIMENSIONAL ANALYSIS OF PANELS

Thorough dimensional analysis of Panels E and F was conducted by Tooling Inspection personnel. For evaluation and comparison, charts of the dimensional analyses of the titanium panels produced in Packs A, B, E, and F are presented in figures 17, 18, 19, and 20, respectively. There is no dimensional analysis of either Pack C, which was severely damaged in the thermal shock process, or Pack D, which curled badly during rolling and did not produce a satisfactory panel.

A study of the four charts reveals one consistent condition which would not be acceptable in production panels, and that is lateral spread. In all four panels, the finish dimensions between the vertical webs are, without exception, greater than the target dimensions. On the average, the spacing is 0.083 inch over the required dimension. However, the webs are not parallel to each other, and the spacing between them tends to increase toward the center of the panel. Assuming that the middle web remains straight, it may be concluded that the outer webs simultaneously move laterally and bow as much as 1/16 inch.

This same pattern is reflected in the width measurements of the face sheets for Panels E and F. In Panel E, the original width of 12.177 inches expanded to an average dimension of 12,294 inches, with a slight increase across the center as compared to the ends. In Panel F, the original 12.175 inches grew to an average of 12.343 inches, with a more pronounced spread in the middle.

A fairly consistent 60 percent reduction in pack thickness is reflected in the finish dimensions of the T-cap thickness, face sheet thickness, and T-height. However, there is more deviation from target dimensions and tolerances than would be acceptable in production panels.

Upon completion of dimensional inspection, Panels E and F were delivered to the laboratory for testing.

Section II

LABORATORY EVALUATION OF TEST PANELS E AND F

Preparatory to laboratory testing, both panels were delivered to a manufacturing department for trimming of the ends. Using the same machine that had been used for previous test panels, the operator successfully trimmed Panel E and one end of Panel F. However, during the cutting of the other end of Panel F, the radiac wheel shattered, causing the damage to the panel shown in figure 21. One rib was machined from Panel F and marked for laboratory testing, as shown in figure 22.

Panel E showed separations along one rib in the web-to-face sheet bond at the tube end after cutting. A crack was observed in one radius of the web-to-face sheet bond near the opposite end of the same rib. After the crack area and the bond separation in Panel E were repaired by fusion welding, as shown in figure 23, it was submitted to Engineering for structural testing. Trim segments from the ends of Panel E were used for laboratory tests.

In a load test in the Engineering Structures Laboratory, Panel E, having been machined to 8-5/8 x 32-3/4 inches, was clamped in a test fixture, as illustrated by figure 24. The load requirement was established at 80,000 pounds. Pressure was applied in increments of 5,000 pounds and was continued until a load of 115,000 pounds had been reached. At this point, the panel deflection reading on the indicator showed 0.258 inch, and the edges of the panel began to buckle, as shown in figure 25. Pressure was released so that the panel could be used for additional testing.

Examination of sections of both panels was conducted by the Production Development Laboratory. The elliptical pattern of cracks that had been observed in previous panels was not evident in either Panel E or Panel F.

TENSILE PROPERTIES

The three tensile specimens obtained from Panel F were tested in accordance with Federal Test Method Standard 151. All specimens met the mechanical property requirements of NAA Material Specification LB0170-177, "Titanium Alloy Sheet, Strip, and Plate (8Al-1Mo-1V)," for duplex annealed material. The tensile test data are as follows:

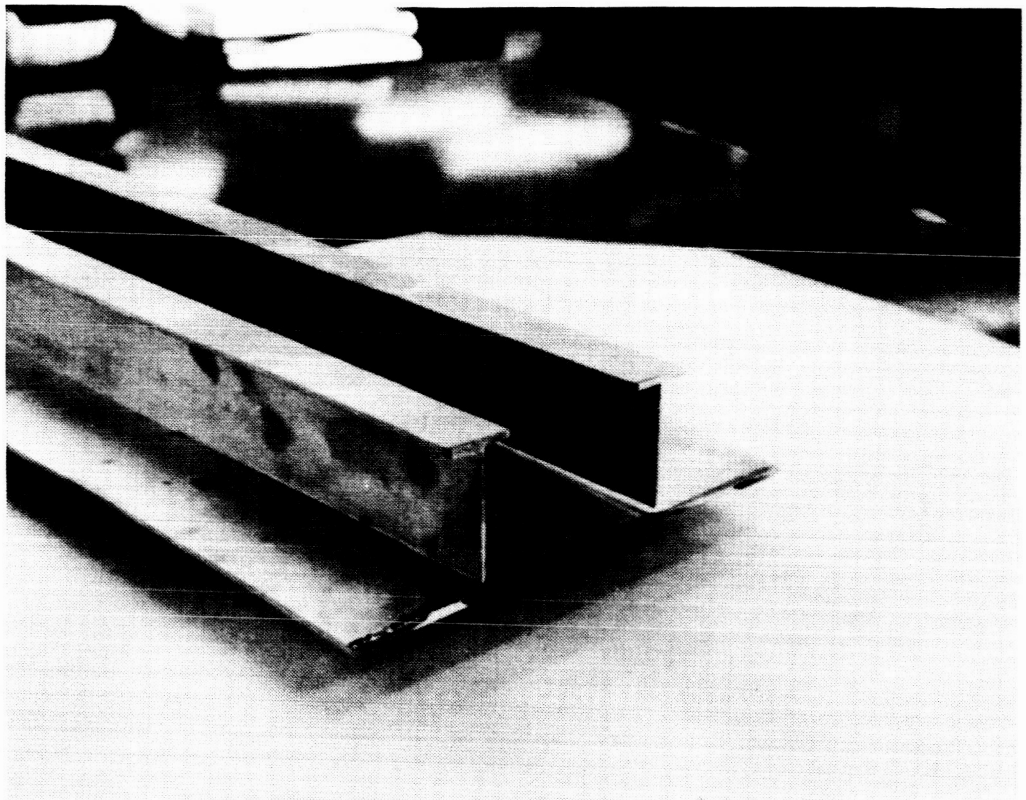


Figure 21. Separation of Web-to-Face Sheet Bond in Panel F

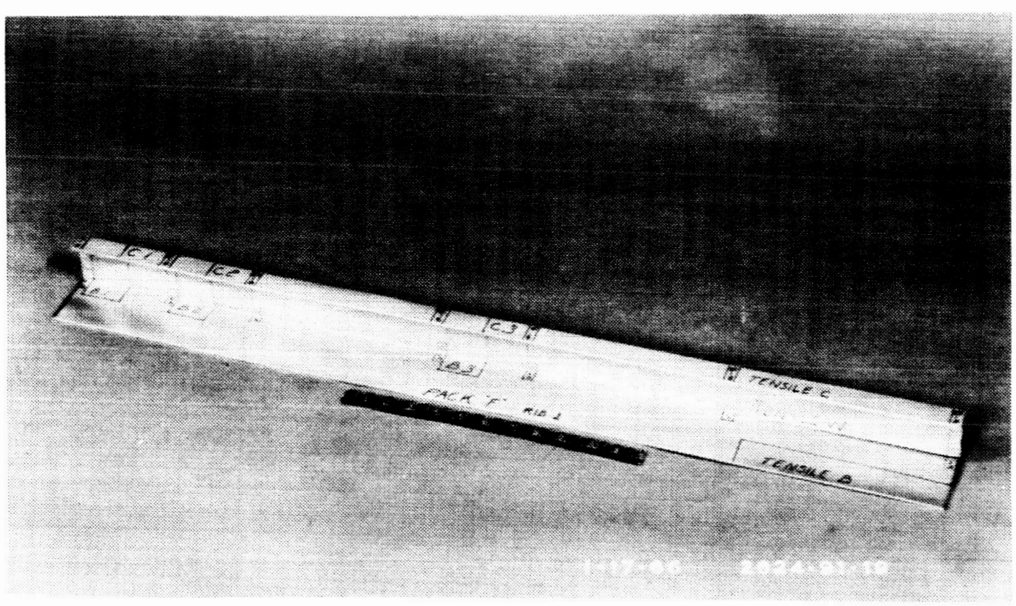


Figure 22. Section of Panel F Marked for Laboratory Testing

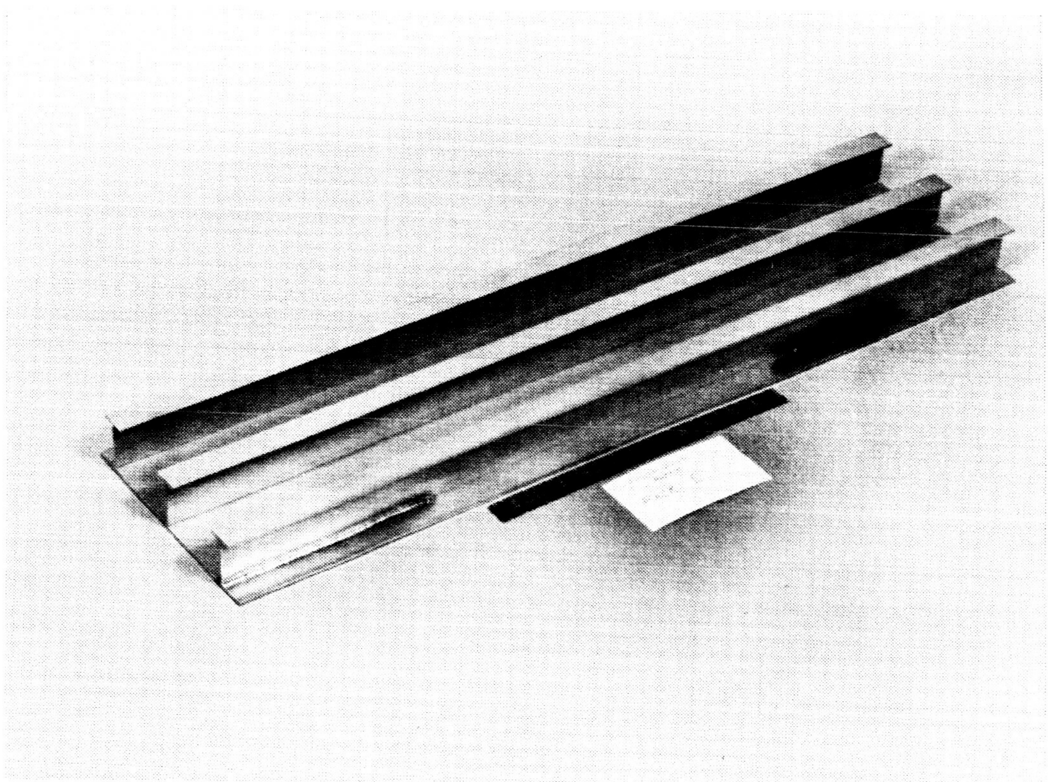


Figure 23. Fusion Weld Repair of Panel E

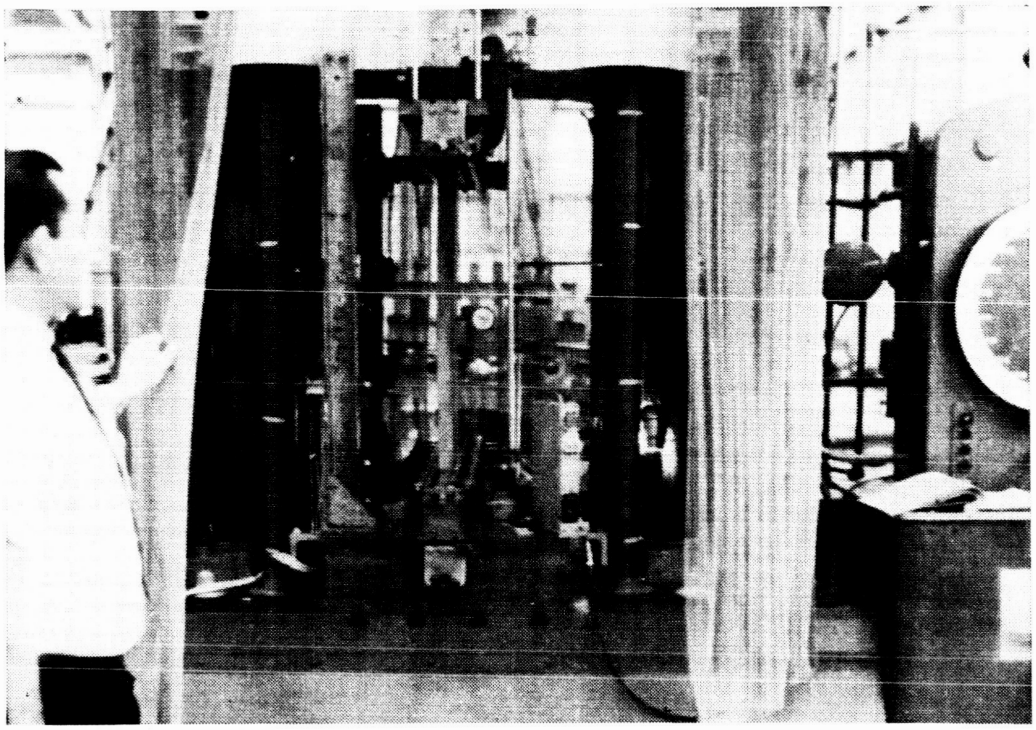


Figure 24. Panel E Load Test

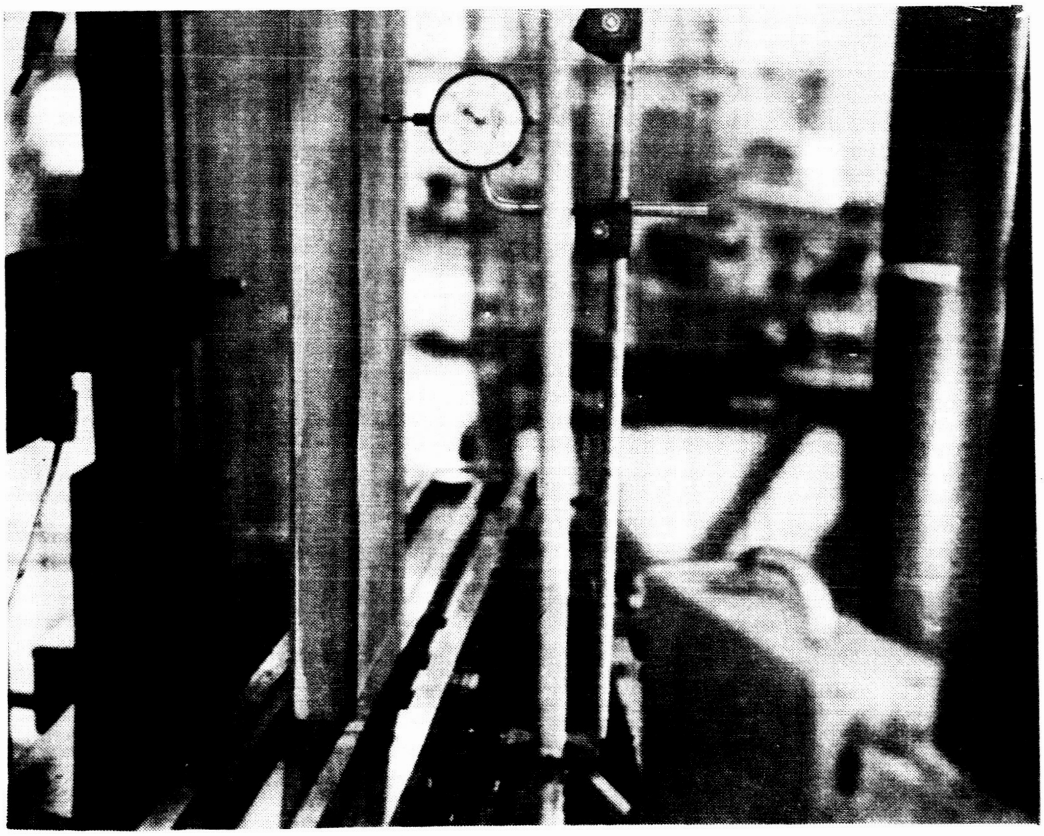


Figure 25. Deflection and Buckling at 115,000 Lbs Load

Tensile Correlation - Panel F

	Yield (Ksi)	Ultimate (Ksi)	Elongation (2% in 2 In.)
Heat D9009 prior to rolling	147.1	155.7	16.4
Face sheet of finished part (heat D9009)	133.7	142.3	17.5
Cap strip of finished part (heat D9009)	140.7	150.3	15.0
Heat G281 prior to rolling	148.5	157.8	14.5
Web section of finished part (heat G281)	133.2	142.8	13.5
Required*	125.0	135.0	10.0

No tensile tests have been conducted on Panel E because the available material was limited to the end sections trimmed from the panel. It was determined that the roll diffusion bonded titanium in these sections was not representative of the main body of the panel.

BOND ADHESION

Six bond adhesion specimens were obtained from the Panel F rib shown in figure 22. Two additional specimens were obtained from rib No. 2 of Panel F, 11 inches from the end opposite the purge tube (not shown). Nine bond adhesion specimens were obtained from the trim ends of Panel E. The specimens were machined to the configuration previously developed for Panel C, as shown on page 56 of Phase I report NA-65-1004, and tested in tension. The resultant bond strengths are listed in the following table:

* Per LB0170-177

Bond Adhesion Tensile Test
Panels F and E

Pack	Specimen No.	Ultimate Ksi
F	B-1	Broke during machining
F	B-2	Cracked during machining
F	B-3	112.8
F	B-4	150.6
F	B-5	168.8
F	C-1	178.6
F	C-2	172.1
F	C-3	179.3
E	B-1	84.1*
E	B-2	145.5
E	B-3	142.8
E	B-4	162.0
E	B-5	144.7
E	C-1	178.1
E	C-2	173.9
E	C-3	138.9
E	C-4	Broke during machining

Of the three web-to-face sheet bonds from Panel F, rib No. 1, B-1 broke during machining, B-2 developed an extensive crack, and B-3 tested at 112.8 ksi. All three cap-to-web specimens from Panel F tested above 135 ksi. Two additional web-to-face specimen from rib No. 2 of Panel F tested above 135 ksi.

All but two bond adhesion tests from the trim segments of Panel E met 135 ksi. One web-to-face sheet specimen failed in shear through a crack in the face sheet during testing. A cap-to-web specimen broke during machining.

INTERSTITIAL CONTENT

The interstitial content of Panel F after fabrication was determined from material from both ends of the Panel. Analysis indicated a greater pickup of oxygen in the purge tube end of the face sheet than in the opposite end. However, all interstitial contents are within the limits of LB0170-177. The oxygen pickup at the two ends of Panel E was nearly equal and considerably lower than Panel F. The results are shown in the following table:

* Failed in shear

Interstital Contents of
Details in Panels E and F

	Hydrogen		Oxygen		Nitrogen	
	Before (1)	After (1)	Before	After	Before	After
Tube end						
Panel E						
Face sheet	0.0055	0.0058	0.089	0.094	0.011	0.010
End opposite tube						
Panel E						
Face sheet	0.0055	0.0081	0.089	0.100	0.011	0.010
Tube end						
Panel F						
Face sheet	0.0055	0.0080	0.089	0.195	0.011	0.023
Web	0.0105	0.0084	0.090	0.136	0.026	0.026
Cap strip	0.0055	0.0088	0.089	0.133	0.011	0.026
End opposite tube						
Panel F						
Face sheet	0.0055	0.0092	0.089	0.156	0.011	0.024
Web	0.0105	0.0076	0.090	0.134	0.026	0.031
Cap strip	0.0055	0.0075	0.089	0.153	0.011	0.026
Required Maximum (2)		0.0125		0.20		0.05

(1) Before and after complete fabrication

(2) Per LB0170-177

MICROSTRUCTURE

Metallographic examinations were made at seven locations along rib No. 1 from Panel F and one additional location from rib No. 2.

In general, the bonds appeared to be very good except for small cracks in the sharp radii of the web-to-face sheet bonds, as shown in figure 26.

Metallographic examinations for Panel E were made from the trim ends segments. The bonds appear to be very good except for some slight beta contamination in the radius of a few of the specimens.

DISCUSSION

The problem of bond separation of Panel F in the web-to-face sheet joint is believed to be due to a combination of factors. The 8Al-1Mo-lV titanium alloy used in this program has shown a tendency to develop cracking during the water quenching used on some of the previous packs to develop a duplex annealed structure. An examination of the two cut ends of Panel F, as shown in figure 22, shows evidence of excessive heat generated during cutting. This heat, combined with the sharp notch and small cracks observed in metallographic examinations of specimens all along rib No. 1 and the quenching effect of the water used during cutting, initiated disbond areas in the web-to-face sheet joints. As the cutting continued, the vibration set up by the abrasive cutting wheel in contact with the now loosened web section resulted in a zipper effect initiating from the small cracks in the radii.

The cap-to-web bonds remained intact during cutting. An examination of figure 22 shows that the cap areas do not have the heat affected zone observed in the face sheet. A study of the metallographic specimens located immediately adjacent to the bond adhesion tests shows good bonding except for the small cracks in the radii of the web-to-face sheet joints as shown in figure 26. A few small pores were detected in both the cap-to-web (figure 27) and the web-to-face sheet bonds (figure 28). The cap-to-web bonds show excellent bond adhesion strength and were apparently unaffected by the small pores in the bond interface.

Panel F bond adhesion, test B-2, was not pulled in tension when visual examination indicated a crack that extended from one radius more than half the thickness of the material, as shown in figure 29.

An examination of metallographic specimen II 1A, immediately adjacent to specimen B-2, and specimen III 1a, located 1-1/2 inches from specimen B-2, shows only small cracks in the radii. It appears that the extended crack in specimen B-2 progressed from a small crack during machining. Web-to-face sheet specimens B-4 and B-5, from rib No. 2 of Panel F, were machined using a technique that prevented vibration in the bond joint. Although test results for B-4 and B-5 were considerably higher than the web-to-face sheet specimen from rib No. 1, the eventual failures appeared to originate from a small crack in the radius. A small crack can be seen in the metallographic specimen immediately adjacent to B-5 as shown in figure 30.

A few small cracks occurred in the cap-to-web joints of Panel F, as shown in figure 31. However, cracks in the cap-to-web specimens of Panel F were intermittent and did not progress during machining.

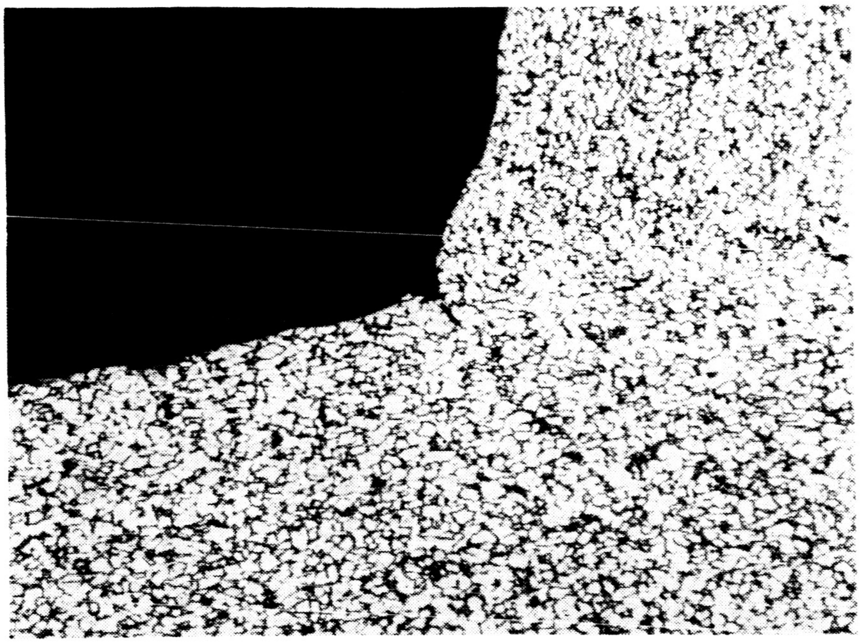


Figure 26. Crack in Web-to-Face Sheet Bond - Panel F

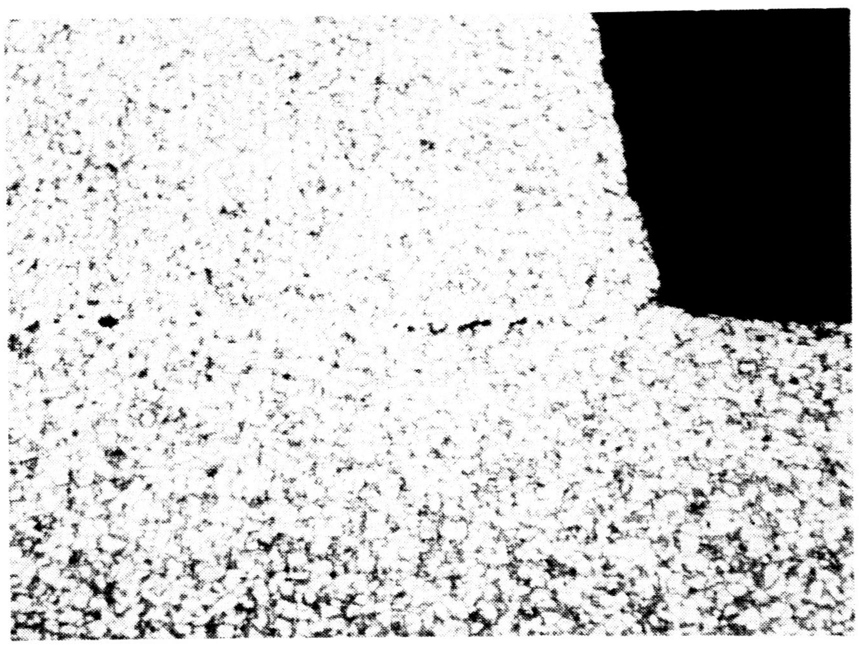


Figure 27. Pores in Cap-to-Web Interface - Panel F

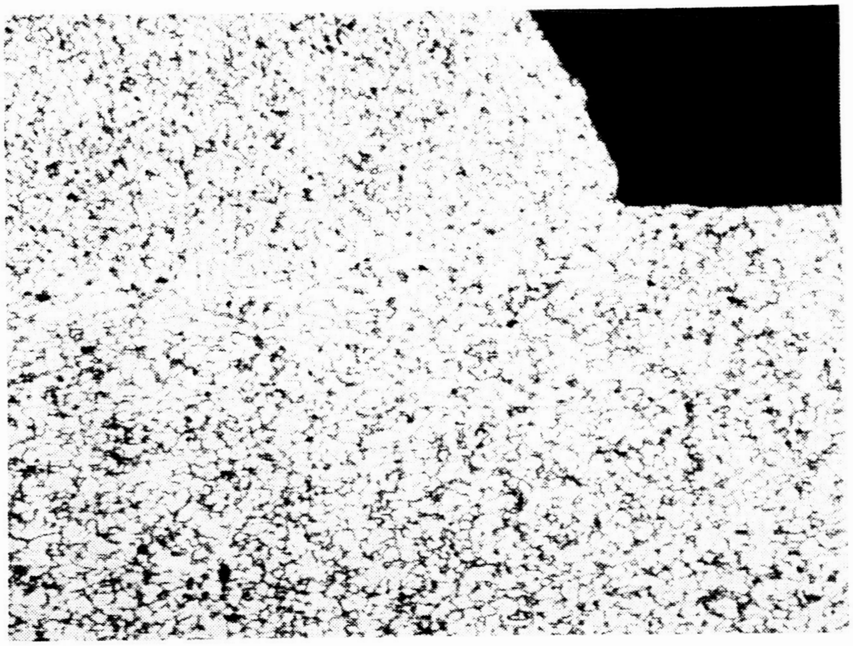


Figure 28. Pores in Web-to-Face Sheet Interface - Panel F

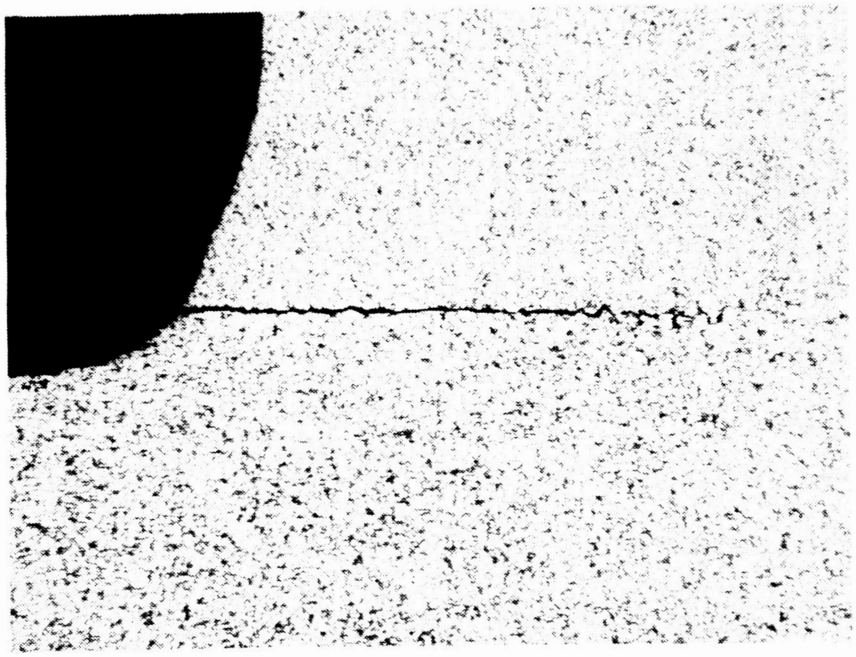


Figure 29. Crack in Bond Adhesion Test B-2 of Panel F

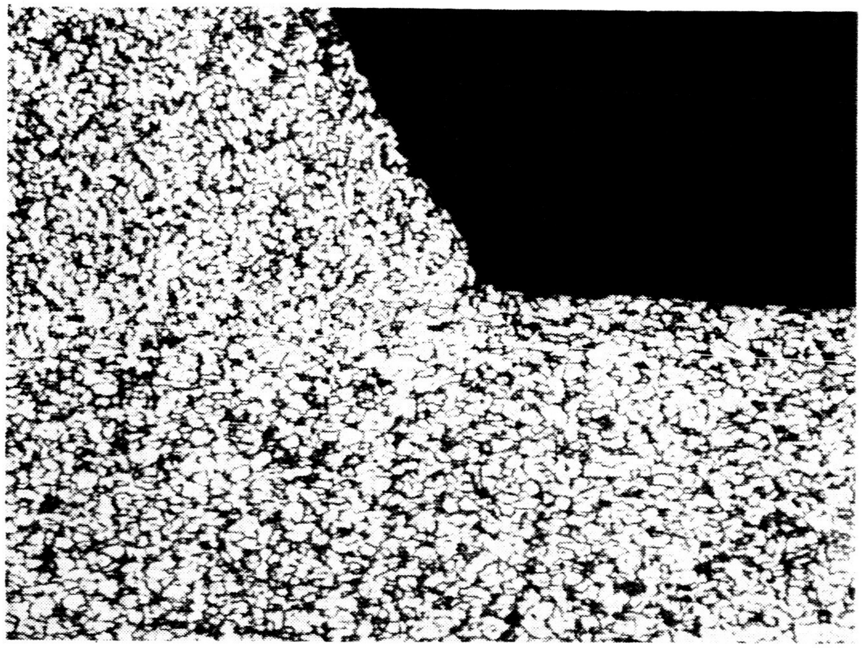


Figure 30. Crack in Web-to-Face Sheet Bond of Rib No. 2

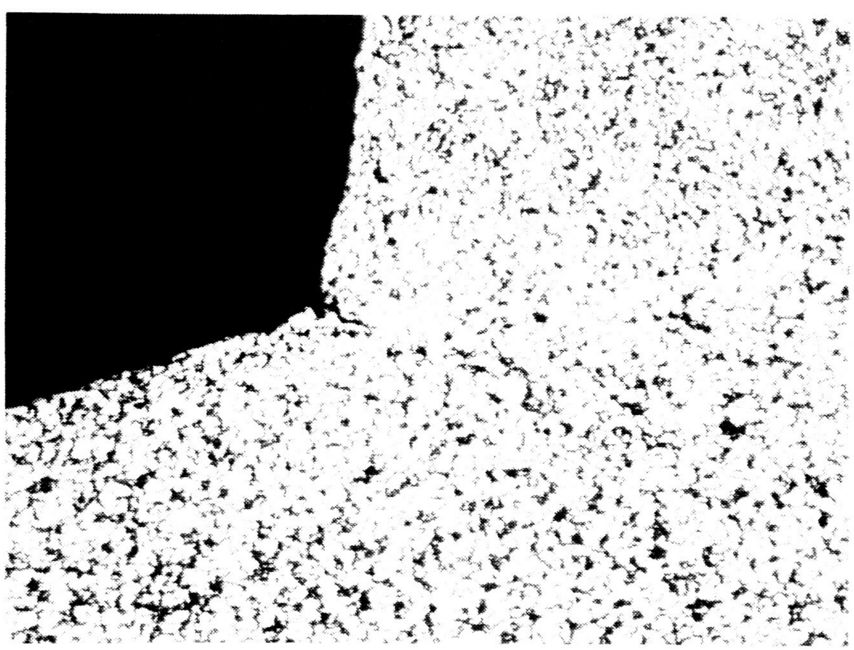


Figure 31. Crack in Cap-to-Web Bond - Panel F

Section III

ROLLING OF A DUMMY FULL-SCALE PACK

When U.S. Steel Corporation proposed that its Gary, Indiana mill roll a steel plate, simulating a Phase III full-scale pack, in order to gain experience in the special heating, handling, and rolling requirements for diffusion bonding of titanium, NAA/LAD felt that a cooperative experiment would benefit the NASA program. Accordingly, an engineering order was released which established the following guidelines:

1. Hot rolled steel plate, approximately 7-1/2 x 102 x 165 inches, to have six holes drilled in specified locations for installation of thermocouples

2. Plate to be heated to 1800°F and rolled to a 60 percent reduction in thickness

3. Rolling to be accomplished in a series of passes programmed to result in a reduction per pass of from 5 percent to 10 percent

4. Finish thickness of plate to be 2.975 (±0.005) inches

5. Minimum plate temperature at conclusion of rolling to be 1600°F, and plate to be air-cooled to 800°F within one hour and then to room temperature

Subsequent discussions between U.S. Steel and NAA personnel resulted in some minor modifications, such as three thermocouples instead of six and 1825°F instead of 1800°F. The plate selected by U.S. Steel was 7 x 108 x 165 inches. It was placed on firebricks in the furnace to provide air space underneath. At the time of charging, the furnace temperature was approximately 1500°F.

Temperature readings were recorded every half hour and, 6 hours after loading, the three thermocouples indicated 1820°F, 1825°F, and 1840°F. The thermocouples were extracted, and the dummy pack was removed from the furnace, as shown in figure 32.

The mobile unit placed the dummy on a preheated steel billet, shown in figure 33, so that there would be no chilling during the transfer to the overhead crane. Figure 34 shows the hot dummy being carried past the scale-breaker mill to the conveyor rolls of the 160/210-inch plate mill. In figure 35, the dummy is shown as it is about to enter the rolls.

Figure 32. Removing Dummy Pack from Furnace

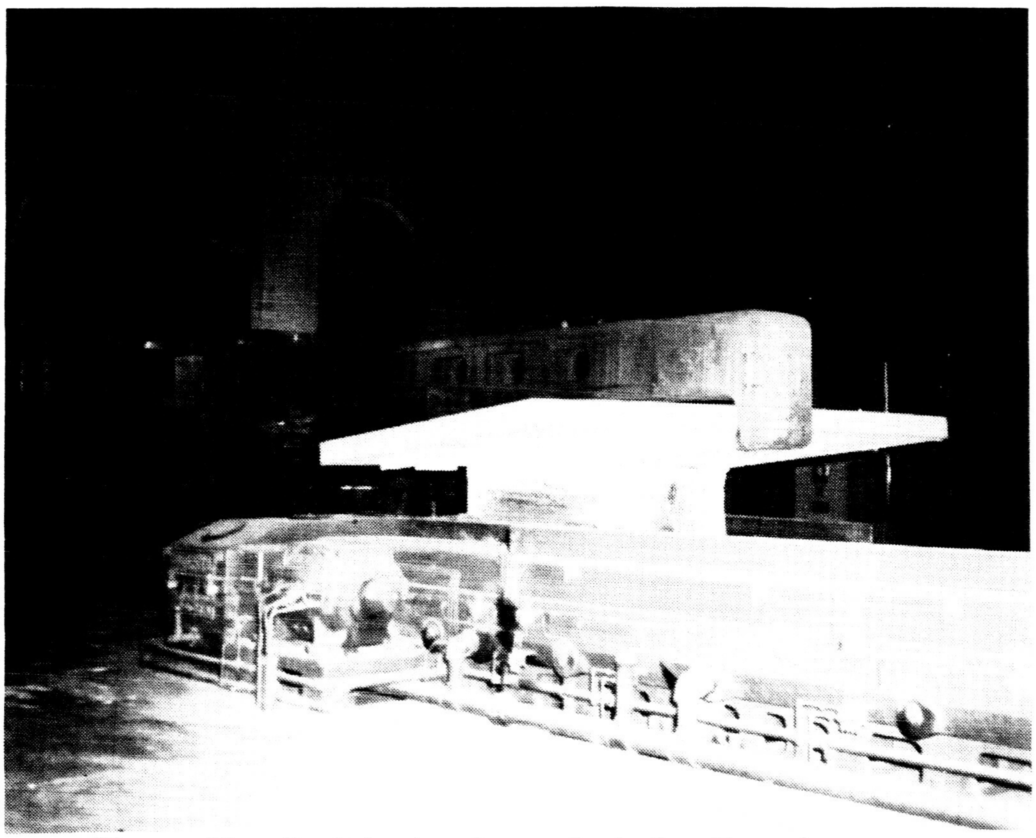


Figure 33. Positioning Dummy Pack for Transfer

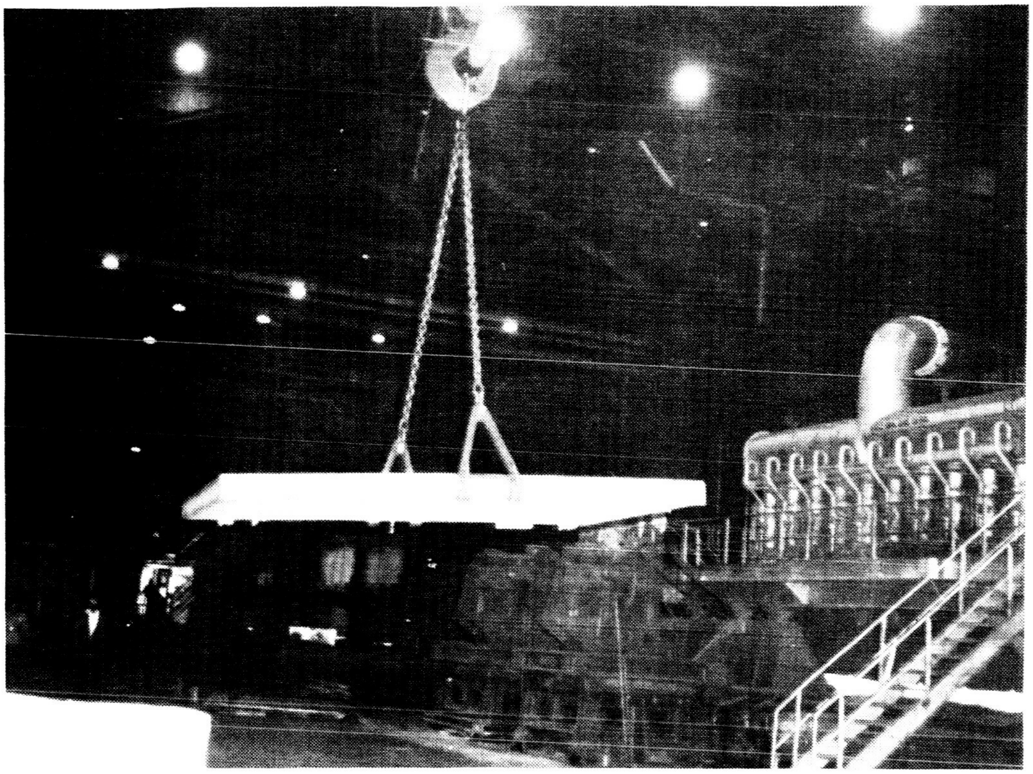


Figure 34. Carrying Dummy Pack to Rolling Mill

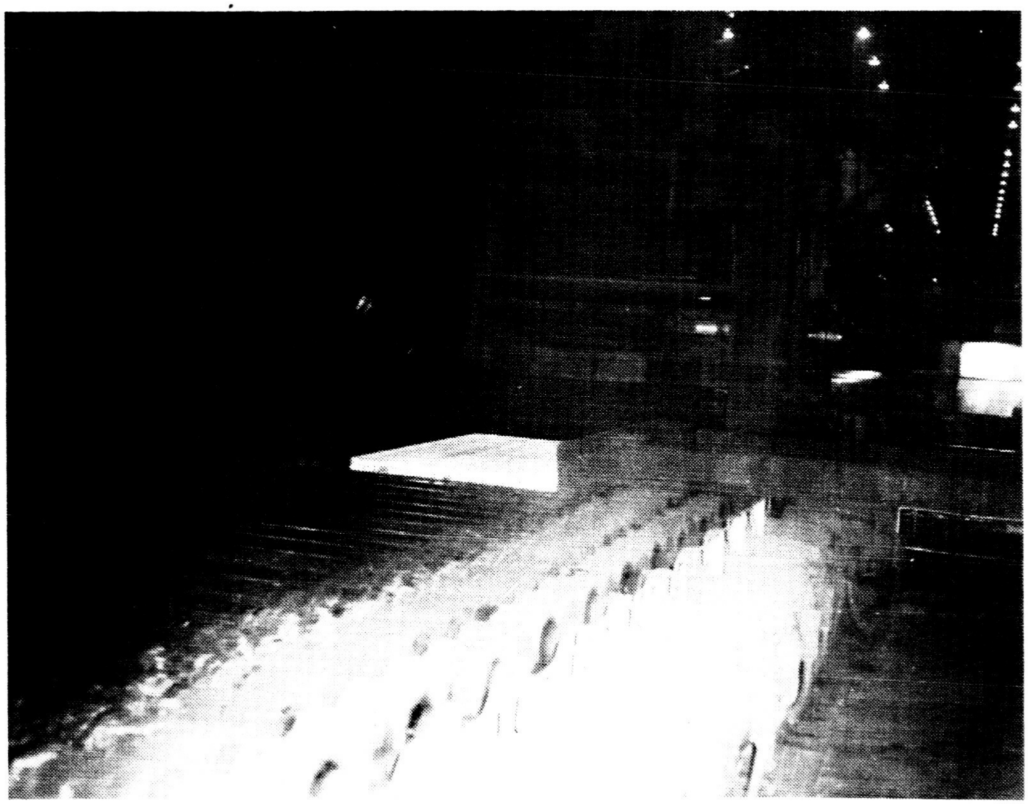


Figure 35. Dummy Pack Entering Rolls

The required 60 percent reduction was accomplished in 13 passes in an elapsed time of 4 minutes. This time included a slight delay after the fifth pass while the rolling sequence was changed because of indicated overpressure on the mill.

As recorded by a surface-contact instrument fixed to an extension arm, shown in figure 36, the temperature of the plate after rolling was 1560°F. The plate was given three passes through the roller levelers, then off-loaded onto a cooling rack. Temperature at this time registered 1450°F.

To determine the cool-down rate, temperature readings were made every 5 minutes. Within 45 minutes, the temperature had dropped to 785°F. This cool-down rate is within the requirements for achieving the duplex annealed condition for 8Al-1Mo-1V titanium alloy.

Thickness dimension of the dummy was measured as 2.980 inches, which is within target tolerance.

Results of the dummy pack rolling test indicate that the 160/210-inch mill at Gary is capable of successfully rolling the two full-scale packs which are being fabricated in Phase III of the program.

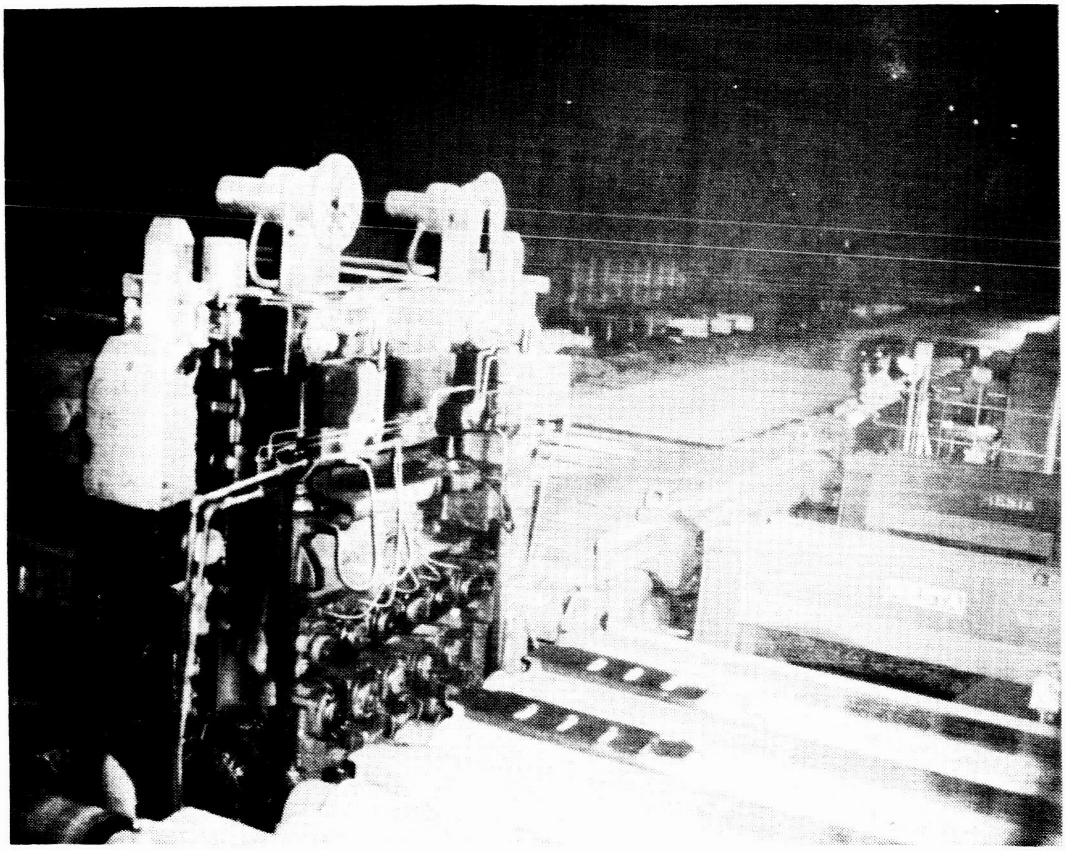


Figure 36. Checking Temperature After Rolling